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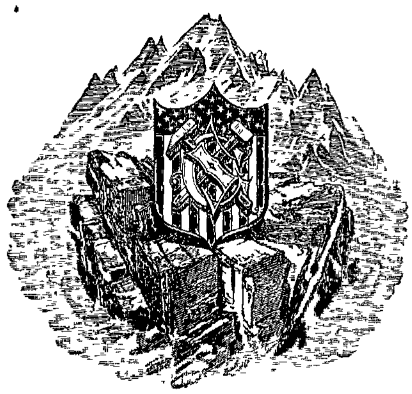
GEOLOGY AND ORE DEPOSITS

OF THE

BRECKENRIDGE DISTRICT, COLORADO

BY

FREDERICK LESLIE RANSOME



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GEOLOGY AND ORE DEPOSITS OF THE BRECKENRIDGE DISTRICT, COLORADO.

By Frederick Leslie Ransome.

OUTLINE OF REPORT.

The Breckenridge district is situated in Summit County, Colo., 60 miles west-southwest of Denver, near the crest of the Continental Divide, and is drained by Blue River, a tributary of the Grand. Placer mining began here in 1860, but it was not until about 1879 that attention was turned to lode mining. During the last five years gold dredging, after many failures, has become established as an important industry.

The production of the district can not be accurately determined. The placers may have yielded $10,000,000 or more and the lode mines probably much less.

The fundamental rocks in the Breckenridge region are granites, pegmatites, gneisses, and schists of pre-Cambrian age. The thick series of Paleozoic rocks present in the Leadville and Tenmile districts thins to the north and west and is not represented near Breckenridge, where the oldest sedimentary rocks, resting directly on the pre-Cambrian, are the brilliantly red sandstones and shales of the "Wyoming" formation, supposed to be of Triassic or possibly of Permian age. Apparently conformable above them is the Dakota, locally a white quartzite with more or less gray shale, and this is overlain in turn by a thick formation of dark shales which probably represent the Benton, Niobrara, and part of the Montana formations of the Upper Cretaceous. In the northern part of the district the Dakota rests on the pre-Cambrian.

The sediments and to some extent the underlying pre-Cambrian rocks are intruded by monzonitic porphyries ranging in composition from siliceous quartz monzonite porphyry to calcic monzonite porphyry or even to a hypersthene-bearing diorite porphyry. Three varieties are distinguished, of which two are mapped. The porphyries are probably derivatives of one magma and were erupted almost contemporaneously, although the quartz monzonite porphyry is younger than the more calcic variety. The intrusive bodies have invaded the sediments mainly as sills, but these are extremely irregular and in very many places the igneous rock cuts across the bedding of the sediments. The intrusions are most numerous and most irregular in the Upper Cretaceous shale.

The bedded rocks incline generally eastward, the average dip being probably not far from 30°. On the west they lap upon the pre-Cambrian rocks of the Tenmile Range, on the other side of which are "Wyoming" and older sediments of the Tenmile district faulted down against the old crystalline rocks by the Mosquito fault. On the east they are themselves dropped against the pre-Cambrian by the Mount Guyot zone of faults, so that one traveling from Breckenridge eastward toward the crest of the Continental Divide finds that the dark Upper Cretaceous shale instead of being overlain in that direction by younger beds is abruptly succeeded by the pre-Cambrian. The absence of the Paleozoic beds from the district and the disappearance of the "Wyoming" formation northward, so that the Dakota lies directly upon the pre-Cambrian, are thought to indicate progressive transgression of the Paleozoic and Mesozoic seas on an ancient land mass which furnished much of the micaceous and arkosic material to the "Weber," Maroon, and "Wyoming" formations. In detail the structure is complicated by the disturbance brought about by the intrusion of the porphyries and by faulting.

The Quaternary deposits in the Breckenridge district may in part be divided into glacial accumulations of Pleistocene age and stream gravels of the Recent epoch. During the Pleistocene there were two advances and retreats of the ice and each has left a depositional record. The earlier is represented by terrace gravels and by what has been called older hillside wash; the later by moraines and low-level gravels or valley trains. The terrace gravels are up to 100 feet or more in thickness and extend from 250 to 650 feet above the present channel of Blue River. They are composed of well-rounded and partly disintegrated material. The older hillside wash is up to 40 feet thick and contains angular fragments instead of waterworn bowlders. Both are auriferous and have been worked by the ordinary hydraulic method.

A typical terminal moraine was formed across the valley of the Blue, just south of Breckenridge, during the second glacial advance. Smaller moraines occur in French Gulch and along the three forks of the Swan.

The low-level gravels are valley trains deposited by water from the melting ice during the second advance and retreat. They occupy the bottoms of the present valleys and are up to 90 feet thick. Ordinarily they range from 25 to 50 feet in thickness. Their material is generally well rounded and coarse, many of the bowlders along the Blue being over 6 feet in diameter near Breckenridge or up to 4 feet near Valdoro. The gravels in French Gulch and along the Swan are finer. The low-level gravels are being exploited by dredging.

Exclusive of the regional pre-Cambrian metamorphism the principal rock changes in the district are (1) local and erratic development of garnet, epidote, sulphides, and other minerals in the sedimentary rocks, probably as a direct result of the intrusion of the porphyries; (2) metasomatic changes in the wall rocks of the ore deposits, especially in the porphyries; and (3) a prevalent propylitic alteration of the porphyries within a few hundred feet of the surface. The essential features of the wall-rock alteration in the monzonite porphyry are a notable decrease in silica, ferric oxide, lime, and alkalies accompanied by an increase in ferrous iron, magnesia, and water with the introduction of sulphides of iron, zinc, and lead and of a large quantity of carbon dioxide. Mineralogically these changes are expressed by the destruction of nearly all the original constituents of the rock and by the development of a ferruginous carbonate, sericite, and quartz, with some pyrite and sphalerite, in their place. This change was effected by waters rich in bicarbonates of iron, magnesium, manganese, and calcium, but poor in silica and alkalies. They carried also sulphur, zinc, and lead, with probably free carbonic and sulphydric acids. In the siliceous quartz monzonite porphyry the change consists in the formation of sericite with little or no development of carbonates. Water, sulphur, and heavy metals are added. The ore-depositing solutions at the places of deposition were evidently different in the two types of porphyry.

Propylitic alteration, involving the development of chlorite, epidote, quartz, and a little pyrite at the expense of the original minerals of the porphyries, appears to be restricted to rocks within 300 feet of the surface. It is thought to be the result of a modified or intensified kind of weathering in which the chemical activity of the ordinary surface waters has been increased by the decomposition of sulphides.

There were in 1909 only two mines, the Wellington and Country Boy, which were steadily producing ore in important quantities. The district in the past has yielded ores of varied kinds and richness, from the native gold of Farncomb Hill on the one hand to the zinc ore of the Country Boy on the other. A large proportion of the output has been partly oxidized argentiferous lead ore. The average value of the shipping ore and concentrates, at smelter prices, may be roundly estimated at about $25 a ton.

The principal fissures in the district strike northeast. The dips are generally steep, the average being probably near to 65°. Those with southeast dip predominate, but there are many with the opposite inclination. As a whole they form a conjugate system. No single fissure is known to exceed 1,700 feet in length and none was formed to the accompaniment of important structural displacement.

The primary deposits may be conveniently but to some extent artificially grouped as (1) veins of the zinc-lead-silver-gold series, (2) stockworks and veins of the gold-silver-lead series, (3) the gold veins of Farncomb Hill, (4) veins in the pre-Cambrian rocks, (5) metasomatic replacements along bedding planes, and (6) gold-silver deposits in quartzite.

The Wellington veins constitute the chief examples of the zinc-lead-silver-gold series, whose members are closely associated with the monzonite porphyry. These veins attain a maximum width of about 15 feet. The filling of the zinc-lead-silver-gold lodes consists chiefly of sulphides, quartz in notable quantity being absent from most of them. In the Wellington mine the principal constituents are galena, sphalerite, and pyrite in various proportions. In the Country Boy the vein, where stoped in 1909, is chiefly sphalerite. These minerals generally form a massive aggregate whose only banding is due to a later infiltration of siderite along small parallel cracks. Here and there the veins are displaced by north-south normal faults of slight to moderate throw.

The ore deposits of the gold-silver-lead series are all in the northeastern half of the district and are as characteristically associated with the quartz monzonite porphyry as are the veins of the preceding group with the monzonite porphyry. A distinctive feature of these deposits is the occurrence of the ore in much-fissured and minutely veined rock, ordinarily quartz monzonite porphyry, rather than in well-defined lodes. The pay shoots are masses of small stringers and impregnated rock and as a rule have no real walls. The type is illustrated by the Jessie mine. No deposit of this group was productive in the summer of 1909, although one (the Hamilton) was being reopened. The ores are of low grade and are generally pyritic, with varying quantities of sphalerite and galena. The veinlets making up the principal part of the ore bodies may contain a little quartz, but they are generally filled almost exclusively with sulphides. These replace the porphyry to some extent, especially the large orthoclase phenocrysts.

The gold veins of Farncomb Hill are remarkably narrow fissure veins that traverse Upper Cretaceous shale, with some sheets of porphyry, and contain isolated pockets of crystalline native gold in a limonitic matrix. The productive veins all lie on the north side of and near a considerable mass of quartz monzonite porphyry, which forms the core of the hill. The rich pockets are confined to a comparatively superficial zone, which probably nowhere exceeds 450 feet in extreme depth from the highest point on the outcrop to the bottom limit of the ore. Their formation appears to have been connected with oxidation and was favored by the structure of the shale, porphyry, and veins, particularly by the slight dislocation of the veins by slips along the bedding planes of the shale. In their original condition the veins probably contained pyrite, chalcopyrite, sphalerite, and galena in a calcitic gangue.

The Farncomb Hill veins owe their rich pockets to the cooperation of sulphide enrichment followed by solution and segregation of the gold in the zone of oxidation.

The Breckenridge ores were deposited through the agency of thermal waters and gases given off from a solidifying monzonitic magma and perhaps cooperating with water of atmospheric or of less definitely assignable origin. Whether the metals in the ores came from the magma or from the rocks invaded by it is not known. The principal gaseous constituents of the magmatic waters were hydrogen sulphide and carbon dioxide.

The ores were probably deposited in early Tertiary time and were enriched throughout the later Tertiary.

The deposits in the pre-Cambrian rocks are generally rather narrow fissure veins carrying auriferous pyrite, in some veins with free gold, in a quartzose gangue. Associated with these, although not all occur in any one deposit, are sphalerite, galena, chalcopyrite, bismuthinite, magnetite, and specularite. Some of these are possibly pre-Cambrian in age.

In Gibson and Shock hills certain beds in the Dakota have been partly or wholly replaced by ore in the form of blanket deposits. Apparently there are at least two such horizons in Gibson Hill which have in the past yielded oxidized or partly oxidized lead-silver ores, but no work has been done on them for some years.

At a few places in the district, especially on Shock Hill and Little Mountain, oxidized gold-silver ores have been found in the form of superficial pockets in the fissured Dakota quartzite.

For the veins of the zinc-lead-silver-gold series the general sequence of deposition was (1) pyrite and sphalerite with probably some galena, (2) galena, (3) siderite (or other iron-bearing carbonate) with small quantities of pyrite and sphalerite, and (4) calcite or barite (rare and nowhere abundant). Though this was the general order, there probably was much overlapping and some unrecorded repetition. Of the paragenesis of the other deposits little can be learned.

The character of the deposits depends to a notable extent on the kind of country rock. The physical character of the Upper Cretaceous shale appears to have especially favored the accumulation of the gold pockets of Farncomb Hill. On the other hand, ores of the zinc-lead-silver-gold series have not been found to any important extent in shale. The lodes of the zinc-lead-silver-gold series are closely associated with monzonite porphyry, whereas the stockworks of the gold-silver-lead series are just as intimately connected with the quartz monzonite porphyry.

Most of the mines show a decrease in the proportion of galena with augmented depth, which means in general a depreciation of the ore. Lead ores of shipping grade probably nowhere in the district extend to a depth of much more than 300 feet. The downward change in the character of the ores indicates enrichment.

The surface of the ground water is very irregular. Its depth generally ranges from zero on low ground to about 200 feet on the ridges unless these are drained by adits. General oxidation appears to be confined to a zone about 200 feet deep and some residual galena may persist at the surface. The oxidized or partly oxidized ores are generally richer in lead, silver, and gold than the purely sulphide ores. The zinc is carried away and is probably deposited in part below the water level. A large part of the galena in the district is believed to have been concentrated by downward-moving atmospheric water.

There are three general classes of gold placers—(1) the bench or high-level placers; (2) the deep or low-level placers; and (3) the gulch washings. The gulch washings were the first worked and yielded much gold to the pioneers in the district. The most noted placers of this group were on the slope of Farncomb Hill. The gold came originally from the veins in the hill. The bench placers are in the terrace gravels and older hillside wash. They have been extensively worked in the past by hydraulic methods, but were not being exploited in 1909. They are generally of low grade.

The deep placers, in the low-level gravels, occupy the bottoms of the present valleys and are now being worked by dredging. The pay channels are generally from 180 to 400 feet wide and average up to about 50 cents a cubic yard. There are spots richer than this, but much of the material worked does not yield 20 cents a yard.

CHAPTER I.

INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

Geologic field work in the Breckenridge district began with a reconnaissance in the autumn of 1908, followed by detailed work from June 20 to September 24, 1909, by F. L. Ransome and E. S. Bastin. The topographic map used by the geologists as a base had been made in 1908 by Charles E. Cook and D. F. C. Moor.

It would be impossible to acknowledge individually all the courtesies extended in furtherance of the work at Breckenridge, but appreciative mention may be made of the specially important services rendered in supplying maps and information, or in devoting time to underground guidance, by Messrs. T. A. Brown, F. C. Cramer, P. L. Cummings, R. W. Foote, O. K. Gaynor, M. M. Howe, Charles Kerns, H. W. Lohman, William Mitchell, John Nelson, Ben Stanley Revett, George C. Smith, and Charles G. Walker. Acknowledgment is due also to Dr. W. S. Ward, in charge of the mineral collection of the Colorado Museum of Natural History, in Denver, for his energy and interest in procuring for use in this report excellent photographs of some of the fine specimens of Farncomb Hill gold generously presented to the museum by Mr. John F. Campion, and to Mr. John W. Finch for courteously placing his unpublished report on the Wellington mine at my disposal.

SITUATION OF THE DISTRICT.

The portion of the Breckenridge district specially studied in connection with the present report and cartographically represented in Plates I and II (in pocket) covers about 45 square miles and includes parts of many irregular areas whose boundaries were early fixed by local regulations and which are individual mining districts in the narrower sense in which that term is used by land surveyors. The more important of these are the Bevan district, including the Wellington, Dunkin, Sallie Barber, and Little Sallie Barber mines; the Union district, including the Country Boy, Jessie, Gold Dust, and Puzzle mines; the California district, including Farncomb Hill; and the Minnesota district, including the Laurium mine. The general position of the area embraced by Plates I and II is indicated by the small-scale outline maps of Plate III and of figure 1. In a broad sense the Breckenridge district includes more than the small rectangular area here considered, the name being commonly applied to all of the country drained by the Blue and its tributaries above its confluence with Snake River and Tenmile Creek, near Dillon. It will frequently be convenient, however, to refer in general to this quadrangular tract as "the Breckenridge district" without denying the right of outlying territory to the same name.

All of the district lies in Summit County, a little northwest of the central point of Colorado. The town of Breckenridge is 60 miles west-southwest of Denver in a straight line and 20 miles northeast of Leadville. By rail, owing to the rugged nature of the country, the distances from these cities are much greater, the length of the narrow-gage line of the Colorado & Southern Railway from Denver to Breckenridge being 110 miles, and from Breckenridge to Leadville 41 miles. The position of Breckenridge in relation to the other metal-mining districts of Colorado (exclusive of iron deposits) is shown in figure 1.

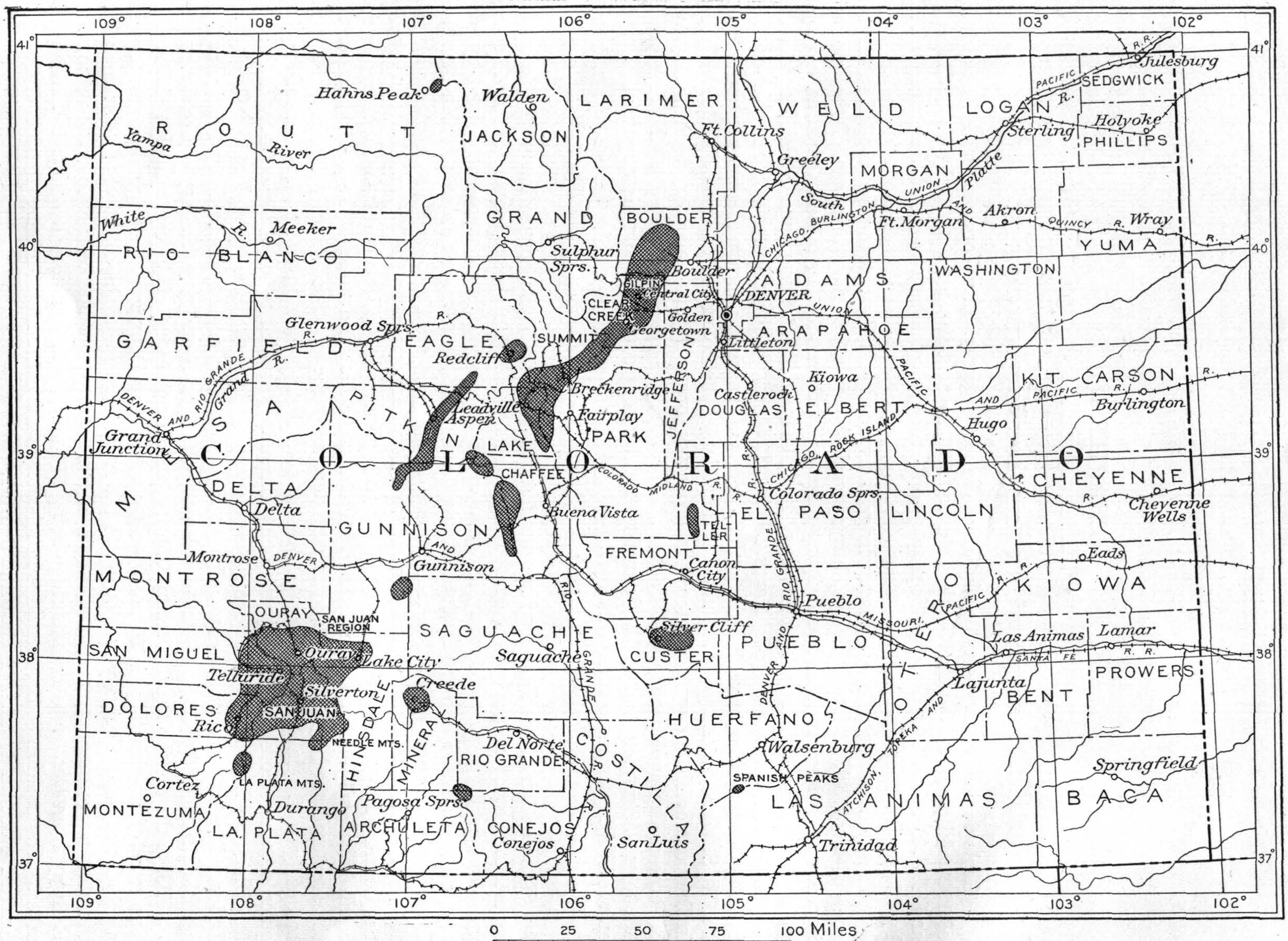


FIGURE 1.—Map showing approximate distribution of the principal silver, lead, and gold regions in Colorado. After Spurr.

TOPOGRAPHY.

THE GENERAL REGION.

The Breckenridge district (see Pl. III) lies about the headwaters of Blue River, on the west side of the main Continental Divide of the Rocky Mountain chain. The town of Breckenridge, at an altitude of 9,577 feet, is at an average distance of about 6 miles northwest of the divide, which from Argentine Pass, between Silver Plume and Montezuma, has a sinuous southwest course over Whale Peak (13,104 feet[1]), Georgia Pass (11,811 feet[1]), Mount Guyot (13,565 feet[1]), Bald Mountain (13,800 feet[1]), (Mount Hamilton on the Hayden map), Breckenridge Pass (Boreas) (11,503 feet[2]), to Hoosier Pass (11,627 feet[2]), 8 miles south of Breckenridge. At Hoosier Pass the divide turns west and passes north of Leadville across the linear uplift variously known as the Park, Mosquito, or Tenmile Range, and along Tennessee Pass to the Sawatch Range.

A notable feature of the Continental Divide east of Breckenridge is the fact that much of it coincides with a gently rolling upland, which is evidently a remnant of a much older topography than that represented by the cirques and ravines notching its edges. S. H. Ball[3] describes what appears to have been originally a part of the same upland, in the Georgetown quadrangle, whose southwest corner (latitude 39° 30′, longitude 105° 45′) lies 10 miles due east of the mouth of Georgia Gulch (Pl. I, in pocket). Ball concluded that this upland dates from late Tertiary time, which is probably a moderate estimate of its antiquity.

On the west and north sides of the divide in the Breckenridge region heads Blue River with its tributaries, Snake and Swan rivers and Tenmile and French creeks. For 20 miles north from Hoosier Pass, to the point where its waters are joined by those of Snake River and Tenmile Creek, the Blue flows through a narrow but fairly open and partly gravel-filled, flat-floored valley, on whose west side the ground rises steeply, within a distance of 4 miles, to the bold, serrate crest of the Tenmile Range (Pls. IV; V, *B*)—as the inhabitants term that portion of the Park Range lying mainly between Blue River and Tenmile Creek and culminating at 14,297 feet in Mount Lincoln, southwest of Hoosier Pass. On the east a belt of mountainous country, widening northward and dissected transversely by French Creek and by Swan and Snake rivers, gives, as a whole, a more gradual ascent to the Continental Divide (Pl. XVII, *B*, p. 76), which is here the crest of the Colorado or Front Range. At Hoosier Pass, as already noted, the main divide crosses the line of the Blue, which heads in two small tarns just northwest of the pass. From the mouth of the Snake, on the other hand, the distance eastward to the Continental Divide at the head of that stream, near Argentine Pass, is about 16 miles.

From the mouth of Snake River the Blue flows nearly northwest for 35 miles and joins Grand River, one of the chief tributaries of the Colorado. The main Park Range continues to bound the valley of the Blue on its southwest side, and along this part of the range, northwest of Tenmile Creek, is locally distinguished as the Gore Mountains.

On the south side of Hoosier Pass, nearly opposite the head of the Blue, is the source of the South Platte, which sweeps south and east across the broad, nearly circular upland basin known as South Park. Into this basin also are gathered, from Breckenridge and Georgia passes, other streams which unite to form Tarryall Creek, a tributary of the South Platte. Still other tributaries from the vicinity of Whale Peak unite as the North Fork (of the South Platte), which after skirting the northern edge of South Park cuts through the Front Range in a deep canyon, followed by the railroad from Denver to Breckenridge, and joins the South Platte only about 8 miles above the point where that river emerges from the mountains to flow northward past Denver.

Ten miles west of Hoosier Pass are the headwaters of the east fork of the Arkansas, which flows southward past Leadville.

It appears from the foregoing description that the Breckenridge district lies in the midst of a rugged part of the great Cordilleran chain, a gathering ground for rivers flowing east and

[1] Elevations determined by the Hayden Survey.
[2] Elevations determined by the Wheeler Survey.
[3] Prof. Paper U. S. Geol. Survey No. 63, 1908, pp. 31–32, Plate III.

west, into the Gulf of Mexico and into the Gulf of California. The region has the topography generally characteristic of the crest region of the Rocky Mountains throughout Colorado. The floors of the principal valleys range from 9,000 to 10,000 feet above sea level and are bounded by precipitous mountains of which a large number are between 13,000 and 14,000 feet in altitude, or rise from 3,000 to 4,000 feet above the valleys. The loftier peaks and ridges have been carved by local glaciation into pinnacles, arêtes, and cirques, and the lower slopes and valleys have had many of their former diversities in relief subdued or concealed by accumulations of glacial detritus, partly in the form of moraines and partly as gravels reworked and deposited by streams.

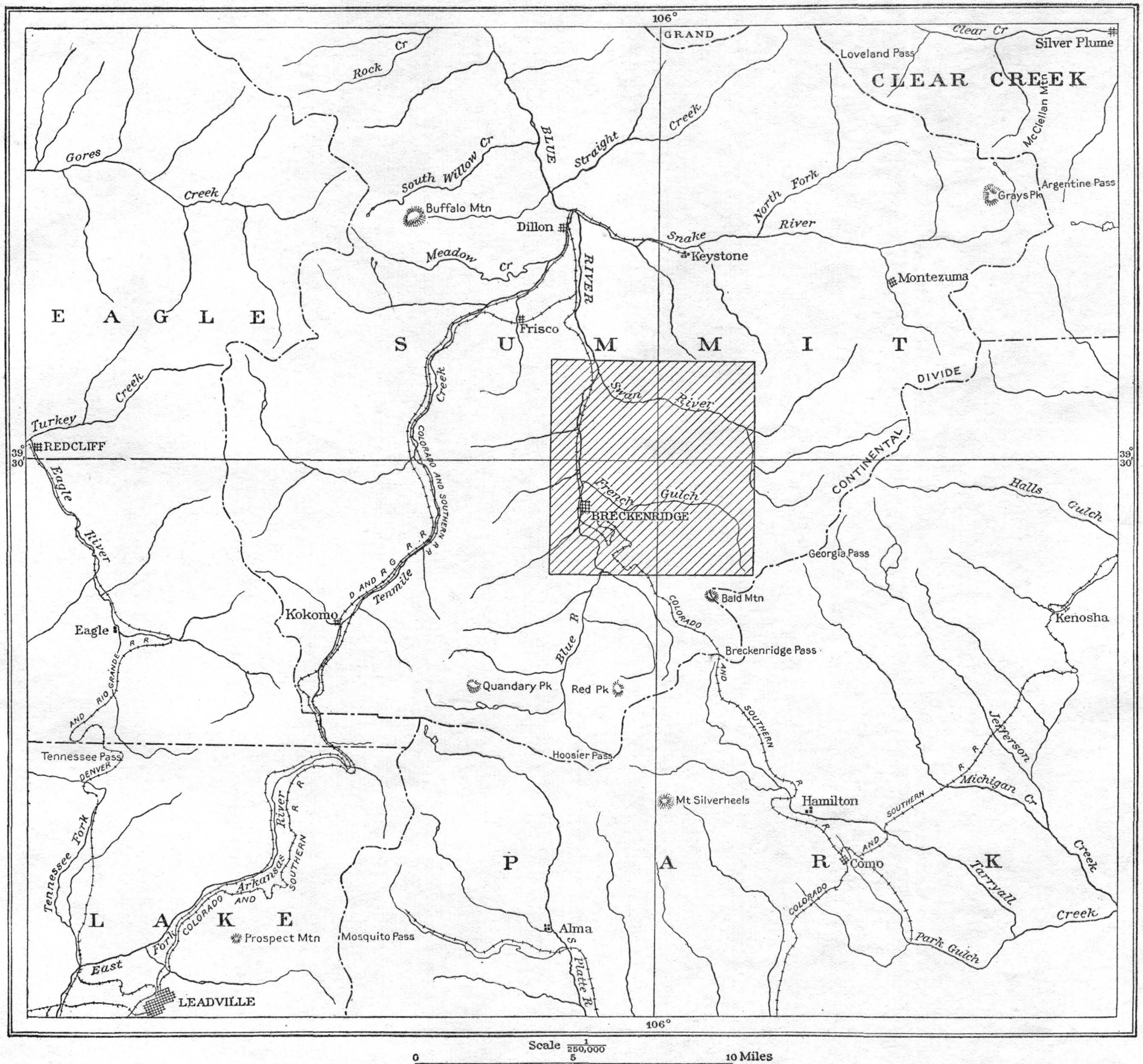
THE DISTRICT.

The part of the Breckenridge district mapped on Plate I ranges in altitude from about 9,140 feet, on the Blue where that river leaves the area on the north, to 13,100 feet, on the northern spur of Bald Mountain, in the southeastern part of the district. The character of this relief, however, is not altogether representative of the general region, for it happens that the boundaries chosen for the present economic study include only a tract of relatively low ground adjacent to the confluences of the Swan and French Creek with the Blue. To the east, south, and west the mountains attain considerably greater heights than any of the elevations shown on Plate I. Thus the slope east of the upper part of French Creek rises precipitously within less than a mile to the summit of Mount Guyot (Pl. V, *A*), which as already noted is 13,565 feet high and is situated on the Continental Divide. Bald Mountain, just south of the spur shown on the map (Pl. I), has an elevation of 13,800 feet. The gentle slopes along the left bank of the Blue steepen rapidly within a mile to the west and sweep up to the crowning peaks and scarps of the noble Tenmile Range (Pls. IV; V, *A*), which easily dominates the landscape from any point of outlook near Breckenridge.

Though less rugged than much of the country about it, the area discussed in this report is in general decidedly hilly, having many steep slopes and little level land except along the larger streams. The topography is the expression of mature erosion, effected for the most part before the earliest locally recorded epoch of glaciation. The work of this erosive cycle is so far advanced that any peneplanation or other special features that might be ascribed to an earlier cycle have been obliterated and there is no recognizable remnant here of the old upland surface noted along the main divide to the east. The effects of glaciation are seen mainly in deposits of morainic material on the sides and bottoms of the present valleys and in the fact that Blue and Swan rivers and French Creek flow in aggraded channels, which in a few places are over 70 feet above their former rocky beds. Some topographic details especially relating to glaciation, such as the hummocky terminal moraine south of Breckenridge and the curious little alluvial flat known as Lincoln Park, will be treated in the chapter devoted to the work of the glacial epoch (pp. 76–79). Although, within the area here specially considered, the former presence of glaciers is recorded chiefly by deposition, the characteristic erosive effects of the ice are well displayed in the Tenmile Range and along the crest of the Front Range.

HISTORY OF MINING.

Breckenridge, like Leadville and many other mining districts in Colorado, owes the discovery of its mineral wealth to that wave of westward emigration which in 1859 surged toward Pikes Peak and broke disastrously along the eastern flank of the Front Range. Not all, however, who shared in the disappointment of that year turned their backs to the West; some penetrated the mountains and found along the higher tributary streams sufficient gold to encourage them to remain. A number of these men began placer operations on Tarryall Creek and established the settlements of Hamilton and Tarryall, about 12 miles southwest of Breckenridge. Tarryall, now deserted, had a population of 2,000 to 3,000 in the early sixties. Another party, consisting mainly of Georgians, ascended Michigan Creek, an affluent of Tarryall, pushed



OUTLINE MAP OF THE REGION ADJACENT TO BRECKENRIDGE, COLO.

Shading shows area covered by Plates I and II.

over the Continental Divide at what is now known as Georgia Pass, and discovered the rich placer ground of Georgia Gulch, on the north side of Farncomb Hill.

During the sixties placer mining was actively carried on in the gulches on the north slope of Farncomb Hill, and the town of Parkville, situated at the mouth of Georgia Gulch, is commonly reported to have had at one time over 1,800 voters. A few timbers projecting from the tailings afterward washed over the site and some obscure graves in the pine-covered moraine fronting the mouth of the gulch are now the only relics of this town. According to W. P. Pollock,[1] Georgia Gulch alone produced about $3,000,000 from its discovery to the close of 1862. Shortly after the settlement of Georgia and American gulches gold was found also on the French Creek side of the hill and for several years the Jeff Davis patch and other placers near Lincoln and the Lillian Vail placer in Nigger Gulch yielded bountiful returns.

Other placers, including the rich and extensive ones of Gold Run, which have probably yielded about $750,000, were opened as facilities for working them improved and Raymond records that in 1870 there were 100 miles of ditches and flumes in the county, most of these being in the Breckenridge region. At this time hand washing had for the most part given place to hydraulic methods, and booming, afterward extensively practiced, was then being introduced. The bed of French Gulch, especially in the neighborhood of Lincoln, was laboriously explored by drifting in these early days.

In 1873 the country around Breckenridge was still almost as wild as when mining began. Thick timber covered the lower slopes of the mountains, roads were few, and the placers along the streams were the principal scenes of activity. The population of the whole county, which until 1883 included what are now Eagle and Garfield counties, did not exceed 350. Breckenridge at that time was reached by stage from Como or from Georgetown by way of the softly beautiful valley through whose verdant meadowland meanders Snake River in the curves that suggested its name.

Silver-bearing lodes were opened on Glacier Mountain, near Montezuma, as early as 1864, but it was not until five years later that any attempt at lode mining was made near Breckenridge. In 1869 some argentiferous lead ore was taken from the Old Reliable vein, at Lincoln, and a small mill, run by an overshot waterwheel, was built on French Creek, close to the mouth of the tunnel. The Laurium mine (now sometimes called the Blue Flag), in Illinois Gulch, appears to have been opened about the same time as the Old Reliable and supplied an argentiferous lead ore that was hauled in wagons to Denver and Golden. The Cincinnati (Robley claim), on Mineral Hill, near Lincoln, was developed in the early seventies and for over 10 years made shipments of high-grade galena and cerusite ore, said to have averaged about 65 per cent of lead and 16 ounces of silver to the ton. As early as 1873 a reverberatory furnace had been erected in French Gulch to treat this ore. Other lead-silver mines operated on a small scale prior to 1880 were the Union, Lucky, and Minnie. The Warrior's Mark ore body was discovered in the late seventies in the reddish sandstones northwest of Breckenridge Pass, where very little work sufficed to uncover an extraordinarily rich mass of silver ore carrying both lead and copper. This proved, however, to be a mere bunch or large pocket, close to the surface, and although much deep work, resulting apparently in the finding of some low-grade ore, was afterwards done in the vicinity of the original outcrop, these developments finally ended in disappointment.

Notwithstanding the fact that rich placers had been washed on the slopes of Farncomb Hill since 1860, it was not until the end of 1879 or the beginning of 1880 that gold was found in place on the Ontario claim; this event was rapidly followed by discoveries on the Elephant, Boss, Key West, Bondholder, Gold Flake, and other now well-known claims on the hill. In view of the extreme narrowness of these veins and their failure to outcrop above their covering of soil the comparatively late date at which they were discovered is not altogether surprising. For about 10 years these wonderful little veins were actively exploited, chiefly by lessees, who riddled the northeast side of Farncomb Hill with tunnels and drifts (see Pl. XXVII, *B*, p. 128) and broke into pocket after pocket of the beautifully crystallized wire and flake gold for which

[1] Cited by Raymond, R. W., Statistics of mines and mining west of the Rocky Mountains, Washington, 1872, p. 328.

this locality is justly famous. In 1885 there were over 100 men working on the hill; but by 1890 the search had lost some of its zest, the masses of gold that had so often adequately rewarded years of labor were less frequently found, and the hill became gradually deserted by all except prospectors such as never recognize defeat or those who are willing to take the lessened chances of finding the residuum of gold that undoubtedly remains. Before the mining activity in this part of the district ebbed to its present low level, however, there was a period, between 1889 and 1898, when considerable work was done by the companies that successively controlled what was originally known as the Ware property, after Col. A. J. Ware, one of the first to operate in the district on an extensive scale. Thus late in 1888 the Victoria Mining Co. built a mill in American Gulch and this was run for a few years on such low-grade ore as could be gathered from the workings and dumps on the north slope of Farncomb Hill. Another mill, now known as the Gold Dust mill, was built by the same company in 1889 on the west side of the Blue near Breckenridge and for a time nine or ten teams were kept busy hauling ore to it from the company's mines, in which numerous lessees were at work. The total capacity of the two mills was 120 tons, but they were not long in operation together. About the year 1894, the Victoria Mining Co. was succeeded by the Wapiti Mining Co., which built many miles of flume, bringing the water from the Middle Swan, and which hydraulicked many of the old dumps and much of the surface material on the north side of the hill.

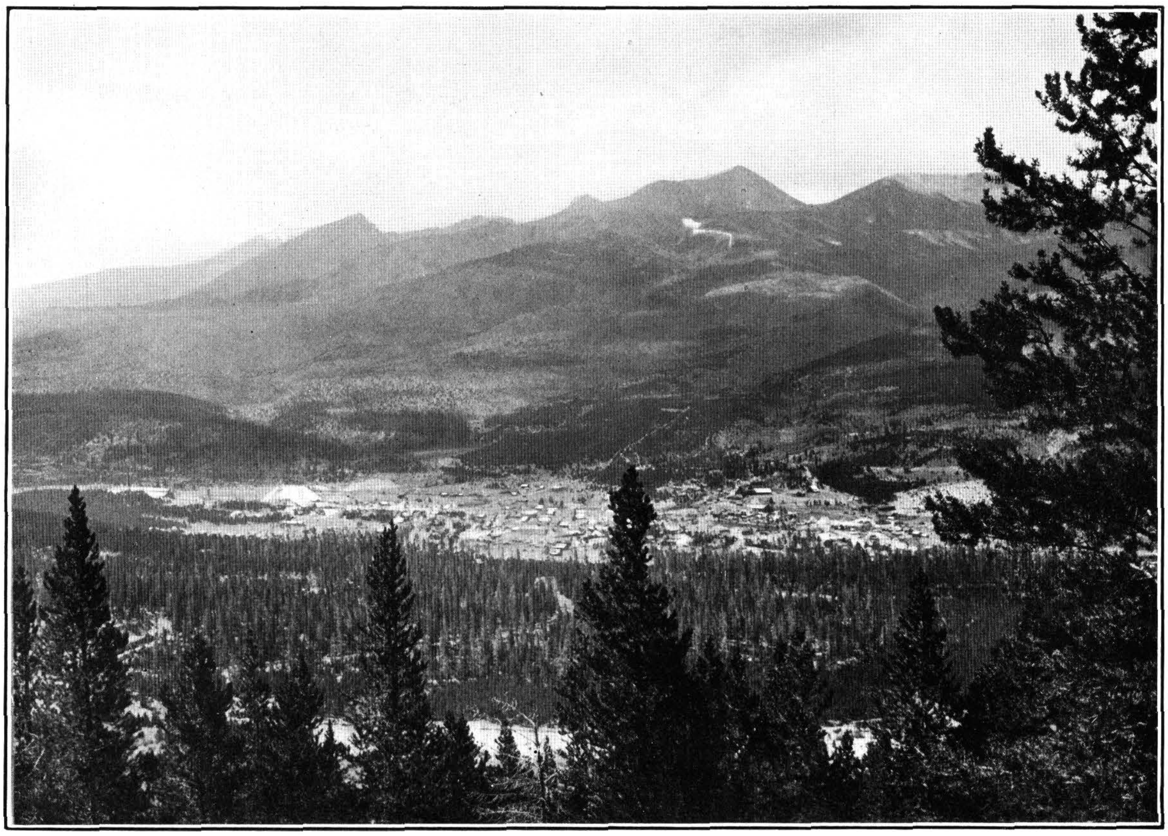
Another part of the district that for a time rivaled Farncomb Hill as a source of gold, although never noted for such beautiful specimens, is Gibson Hill. Here the first event of note was the discovery of the Jumbo lode by E. C. Moody in the summer of 1884, this being followed by active prospecting all over the hill. A settlement known as Preston was established on the north slope and for several years the Jumbo, Buffalo, Extension, and Little Corporal mines produced a large quantity of comparatively low-grade free-gold ore that was milled in part at Preston and in part at what was known as the Eureka mill, at the mouth of Cucumber Gulch, below Breckenridge. About the year 1886 Moody began work on the Seminole and other claims north of Gold Run, afterward developed into the Jessie mine. Before 1890 production had begun also from the Hamilton and Cashier mines.

Meantime, while the gold deposits were being developed the silver-lead mines were not idle. In 1883 the Cincinnati was the largest mine on Mineral Hill, but it was soon surpassed by the Lucky. In the middle eighties Lincoln was a thriving town in which three small mills were active, treating about 60 tons of ore a day. In one of these was concentrated the first ore taken from the Oro mine, in 1887. In the following year the owners of the Oro built their own mill at the mine, which soon became one of the most productive in the district. Another mine that came into prominence about this time is the Iron Mask, situated on the west side of the Blue, in Shock Hill. From this mine shipments of high-grade silver-lead ore began in 1888 and continued with few interruptions for about 10 years. Other mines shipping in 1889 or 1890 were the Ohio, on Shock Hill; the Kellogg and Sultana, on Gibson Hill; the Washington, Dunkin, and Juniata, on Nigger Hill; the Mountain Pride, at the head of Illinois Gulch; the Oro and Lucky, on Mineral Hill; the Victoria (Wapiti) group, on Farncomb Hill; and the I. X. L., on the Swan. Just beginning noteworthy development and production at this time were the Puzzle, Ouray, Country Boy, and Wellington mines. In 1891 the Boss and Gold Flake mines, on Farncomb Hill, yielded some rich masses of crystalline gold. Among the events of 1892 was the organization of the Jessie Gold Mining & Milling Co., which took over the property of the Gold Run Mining Co., and began the building of a new mill at the Jessie mine. The Extension Gold Mining & Milling Co. undertook in the same year the thorough development of what had hitherto been generally known as the "Fair property," near the Jumbo mine.

About the year 1896 shipments were resumed from the Mountain Pride, and this mine shortly afterward began extensive development and in 1898 was the leading producer in the district. This preeminence, however, was not long maintained and the mine had been idle for a number of years when visited in 1909. The Cashier and Jessie mines were actively worked and produced large quantities of milling gold ore in the late nineties, but work in both was abandoned some years ago. In 1909 the only mines producing were the Wellington, Country

A. TENMILE RANGE FROM ROAD ABOUT A MILE NORTH OF BOREAS.

View is across the valley of the Blue and shows the peaks and cirques just north of the head of that stream. Quandary Peak appears at the left. See page 16.



B. BRECKENRIDGE AND THE TENMILE RANGE FROM GIBSON HILL.

The distant gentle slopes on the left represent nearly the surface upon which the Paleozoic sediments were deposited. Below them, near the town, is the terminal moraine on the Blue. The white dumps near it are composed of bowlders from the Gold Pan elevator pit. The wooded spur in the foreground, between French Creek and Breckenridge, is composed mainly of terrace gravel. See page 72.

Boy, and Sallie Barber. The Hamilton mine, after being productive for many years, was abandoned about the year 1902. It was reopened in 1909 and promises again to become important. During this same year also work was resumed in the Puzzle and Gold Dust workings, from which and from the Ouray mine large quantities of high-grade silver-lead ore with some gold were stoped during the 20 years following 1885. With these exceptions, all the old mines that have in the past contributed to the output from the district were unproductive in 1909 and most of them were in an abandoned or ruinous condition. At some, such as the Washington mine, none of the workings could be entered.

A visitor to the district, seeing the numerous deserted mines and forgetting that at no one time were all in simultaneous operation, is likely to exaggerate the difference between the present state of lode mining and former periods of more general activity. A review of the history of the district year by year, however, shows many vicissitudes. There have undoubtedly been periods when the producing mines were far more numerous than at present, when more mills were active, and when outlying settlements like Lincoln and Swan City had busy populations. Yet not only did the hills, even in those prosperous times, display on their slopes the obvious traces of abandoned enterprises, but they also bore within them unsuspected riches whose discovery later was to give rise to fresh activity.

The ordinary modes of placer mining, particularly hydraulic washing, booming, and bedrock drifting, continued to be actively practiced up to about the year 1900 and then gradually fell into disuse. In 1909 none of this work was in progress, except at one place on the upper Swan, where an attempt was being made to convert a bedrock drift into a sluice connected with an open pit; attention had been diverted from the high-level and superficial placers to those amenable to the modern method of dredging.

It was in 1895 that Mr. Ben Stanley Revett, recognizing the possibility of working the deep gravels along the main streams, began by attempting to sink a shaft to bedrock on the Swan, near the mouth of Galena Gulch. This shaft, owing to the large quantity of water present, was not successful. He then undertook to test the gravels with an oil drill, this probably being the first application of such an implement to prospecting in Colorado.

In 1898 the American Gold Dredging Co., organized in Boston under the laws of Michigan, built two dredges on the Swan, but these, planned in accordance with New Zealand experience, proved unable to excavate the deep and coarse gravel near the mouth of Galena Gulch. In this year also the same company set up two Evans hydraulic elevators on the same stream. On the Blue, near the mouth of Cucumber Gulch, Pence & Miller were trying to sink a placer pit, using first hydraulic elevators and then steam pumps. At 30 feet in depth the pit had not reached bedrock. In 1899 the Blue River Gold Excavating Co. began work on the Blue, about 2 miles north of Breckenridge, with two dredges of the orange-peel type. These were failures. Toward the end of the year the North American Gold Dredging Co. built one Risdon and one Bucyrus dredge on the Swan and dismantled the two first constructed. The new boats, the larger having a capacity of 2,500 cubic yards a day, were operated for a few years, but were never fully successful and were finally abandoned. The gravels having been found difficult to handle with the lightly constructed dredges then in use, the Gold Pan Mining Co., organized in December, 1899, with a capital of $1,750,000, acquired 1,700 acres of placer ground and undertook to work the bed of the Blue, at the south end of the town of Breckenridge, by using hydraulic elevators. This company spent $750,000 in cash and gave 400,000 shares of stock, par value $1 each, to pay for the construction of 3 miles of 8-foot ditch and a connecting pipe line having a capacity of 6,000 miner's inches, the erection of machine shops, and actual excavation. Bedrock was reached in October, 1902, at 73 feet. But this ambitious project, like its lesser predecessors, failed to wrest riches from the river channel, although it has left an enduring monument to itself as well as an instructive warning to others in the huge pile of bowlders, many of them over 6 feet in diameter, that now overlooks the town. (See Pls. IV, *B*, p. 18; XVIII, *B*, p. 78.) In the prospectus issued by the company the productive life of the ground had been estimated at 40 years, the average value of the gravel at 60 cents a yard, the cost of working at 10 cents a yard, and the total profits at $80,000,000. The plant has not proved entirely useless; part of the capacity of the ditch and pipe line has been utilized for lighting the town and the machine shops have proved a valuable adjunct to the gold-dredging industry.

In 1905 the American Gold Dredging Co. was operating one dredge on the Swan, but this company appears to have done little after that, and in 1907 its property was acquired by the Colorado Gold Dredging Co. In 1905 Mr. Revett, acting as trustee for the Reliance Gold Dredging Co., unincorporated, began the construction of a double-lift dredge on French Creek. This, although it was originally driven by steam, has been partly remodeled and is still in use. In 1908 the Colorado Gold Dredging Co. began dredging at Valdoro with two Bucyrus boats. One of these has been advancing steadily up the Swan, and the other, after going down this stream, has turned up the Blue. The latter was operated in 1909 but not in 1910. A fourth dredge, built by the French Gulch Dredging Co., was launched in French Gulch in the autumn of 1908 and has since been successfully at work. It thus appears that in the establishment of gold dredging as an important and profitable industry the district has gained at least one very material offset to the decline, probably in part temporary, of some other forms of mining.

This brief historical sketch would not be complete without a reference to the improved facilities for handling ore and concentrates afforded by the completion of the narrow-gage South Park & Pacific Railway, as it was then called, from Denver to Breckenridge in 1880, with its extension to Leadville in 1881, and to the advantages given to all kinds of mining by the introduction into the district during the last two years of electric power by the Central Colorado Power Co. and the Summit County Power Co.

PRODUCTION.

Complete statistics of production for the Breckenridge district or even for Summit County are not obtainable. For certain years the output of Summit County is included with that of Park County in the statistical volumes of this Survey and of the Mint. Even where separate figures are published for Summit County it is impossible to distinguish the production of the Breckenridge district from that of the Robinson and Montezuma districts. Of late years most of the placer gold from Summit County has come from the Breckenridge district, which in 1908 yielded $146,098, or 79 per cent of the total placer output of Colorado, amounting to $184,935. The published statistics, however, do not always give the placer yield of Summit County separately, this being combined in 1906, for example, with gold from siliceous ores, in order to conceal individual mine production.

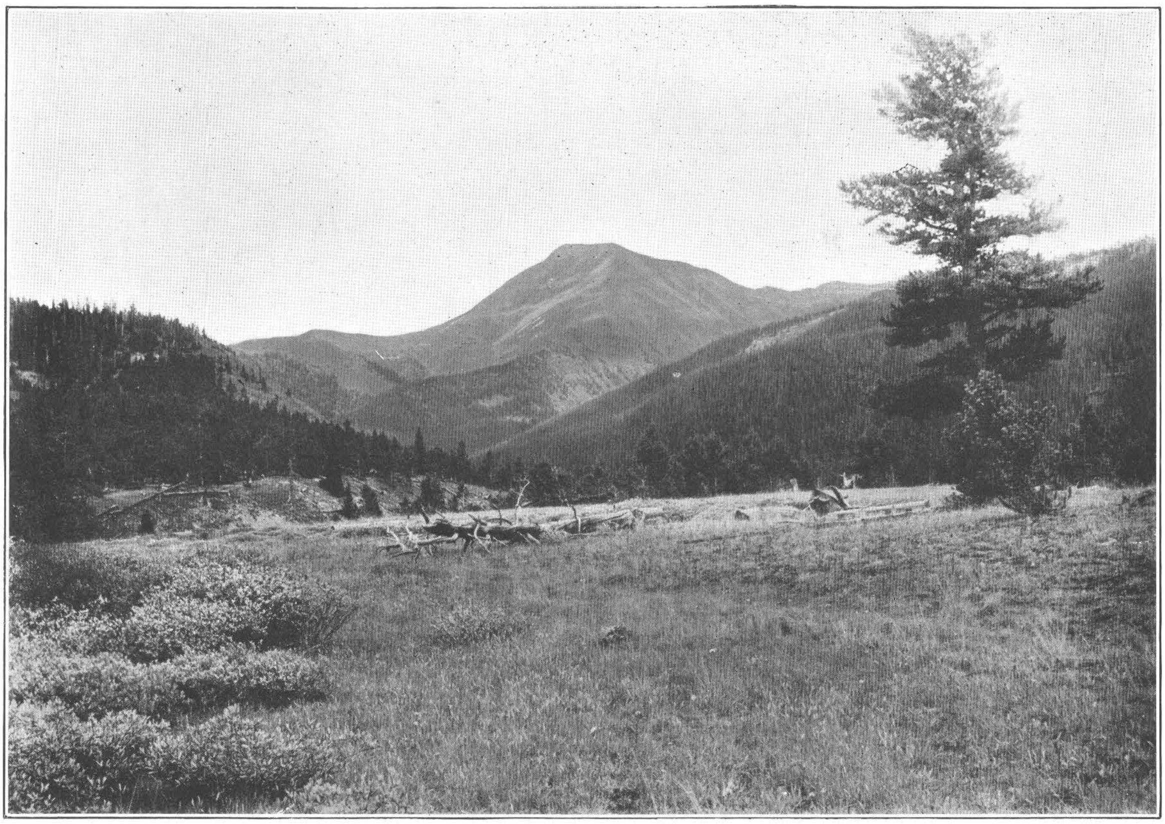
On February 28, 1885, the Summit County Journal published the following statement of placer production from Summit County:

Placer gold produced in Summit County, Colo.

Prior to 1870	$5,500,000	1878	$166,000
1870	100,000	1879	100,000
1871	70,000	1880	50,000
1872	60,000	1881	60,000
1873	101,000	1882	55,000
1874	76,500	1883	105,000
1875	72,500	1884	205,000
1876	150,000		
1877	150,000		7,021,000

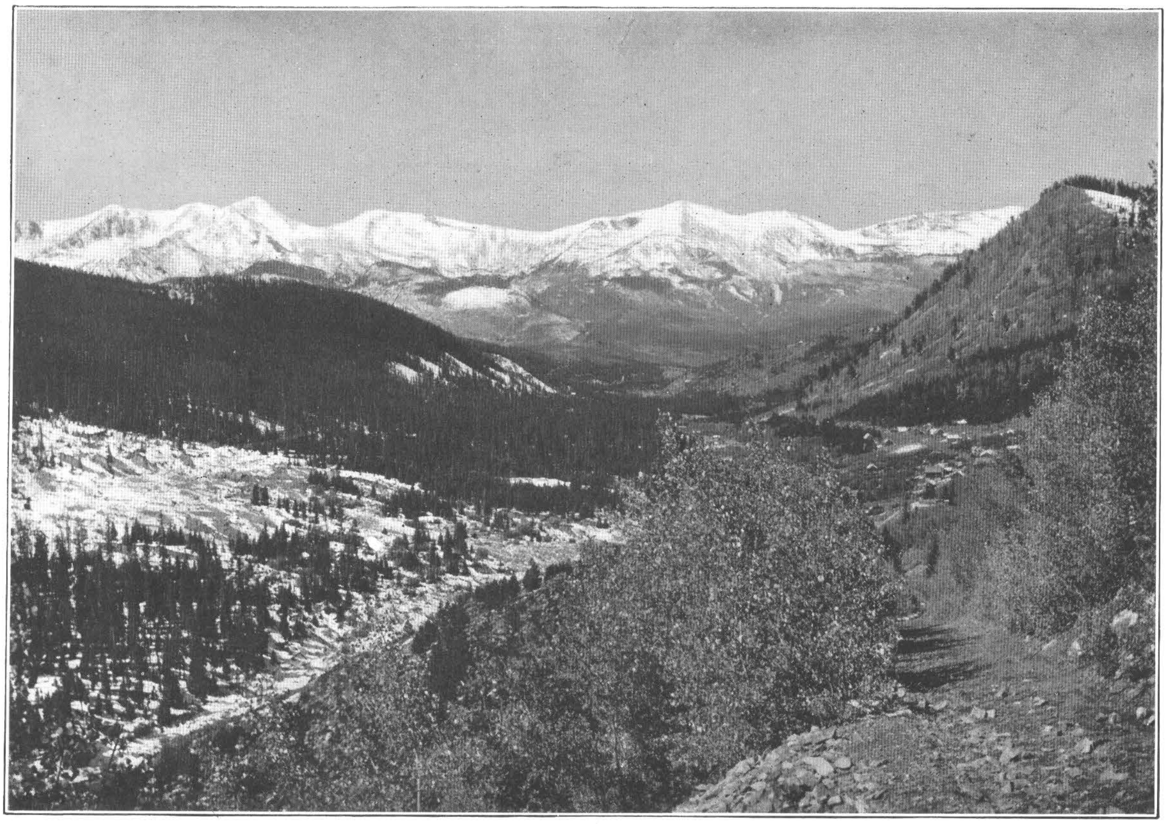
It is not known how these figures were obtained nor how accurate they are, but inasmuch as Georgia Gulch alone is reported to have produced $3,000,000 by the close of 1862[1] and the Mint report for 1880 gives the placer production for that year as $50,000, the unknown statistician of the Summit County Journal does not appear to have exaggerated the output from the placers. The same local paper records in its issue of January 3, 1891, that 4,034 tons of ore and concentrates were shipped from Breckenridge in 1889 and 4,923 tons in 1890. The value is not given, but on the assumption that it averaged $25 a ton the output from mines would

[1] Raymond, R. W., Statistics of mines and mining, Washington, 1872, p. 328.



A. MOUNT GUYOT FROM LINCOLN PARK.

The flat alluvial surface of the "park" is shown in the foreground. Beyond it is French Gulch, the main branch of which turns to the right of Mount Guyot. The lower slopes of the peak are shale, but the upper part, extending down nearly to timber line, is porphyry. See page 57.



B. FRENCH GULCH FROM FARNCOMB HILL.

In the distance is the Tenmile Range. The bold eminence to the right is Mineral Hill. Just under it is the nearly deserted settlement of Lincoln, and across the gulch, on the left, is the old Jeff Davis placer. On the dark wooded slope behind it, which leads up to Bald Mountain, at a point where the trees along the crest appear thinner than elsewhere, are the Sallie Barber and Little Sallie Barber mines.

be $100,850 in 1889 and $123,075 in 1890. In 1905 the total output of the district was about $280,000,[1] and in 1907 the yield from seven mines (all that were productive) was $175,201.[2] In 1908 the total production from the mines was $129,173,[3] and in 1909 it was $538,704.[3]

These fragmentary figures, unsatisfactory as they are, serve to indicate the relative productivity of the district. At no time, unless perhaps during the first few years of shallow placer work, can this be called large.

The output by metals in 1909 from mines and placers, as returned by the producers to this Survey, was as follows:

Quantities of metals produced in the Breckenridge district in 1909.

Gold from placers .... fine ounces..	19,574.27
Gold from ores .... do....	1,746.48
	21,320.75
Silver from placers .... fine ounces..	5,314.00
Silver from ores .... do....	73,241.00
	78,555.00
Copper .... pounds..	2,508
Lead .... do....	3,513,698
Zinc .... do....	5,978,167

The gold and silver produced from the placers of Summit County during the last three years has virtually all come from the dredges working in the Breckenridge district. The figures, taken from the volumes of "Mineral Resources" issued by this Survey, are as follows:

Recent production from the Breckenridge placers.

Year.	Gold (ounces).	Silver (ounces).
1907	1,800.23	662
1908	7,032.27	1,638
1909	404,636.00	5,314

The notable increase in 1909 was due to the successful operation of new dredges.

LITERATURE.

The following are some of the important geologic publications relating to the Breckenridge region:

RAYMOND, R. W., Statistics of mines and mining west of the Rocky Mountains, Washington, 1872, 1873, 1874.

Notes on early history and development.

PEALE, A. C., Report on the geology of the South Park division: Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, pp. 194–273.

Dr. Peale ascended Mount Guyot from Georgia Pass. He describes the peak as formed of eruptive granite and gives a section (Pl. VI, fig. 4) showing it separated from the Archean gneisses to the east by some altered shale and quartzite. The high hills south of Mount Guyot, between Michigan and Tarryall Creeks, are described as made up of a "porphyritic volcanic rock, approaching the character of a phonolitic trachyte." This is mainly the quartz monzonite porphyry of the present report. It is intrusive into Cretaceous shale which also forms a considerable part of the hills mentioned.

On Tarryall Creek Dr. Peale noted quartzite (evidently the Dakota) dipping under the porphyry, and this is shown on the Hayden geologic map as extending continuously past Breckenridge Pass (Boreas) to the town of Breckenridge. Under the quartzite were noted red beds, supposed to be Triassic, forming the bedrock of the auriferous gravels of Tarryall Creek.

Dr. Peale gives a detailed section of the beds exposed on the east slope of Silver Heels Peak, 10 miles south of Breckenridge. All of Dr. Peale's work appears to have been south or east of the Breckenridge district.

[1] Mineral Resources U. S. for 1905, U. S. Geol. Survey, 1906.
[2] Mineral Resources U. S. for 1907, U. S. Geol. Survey, 1908, p. 140.
[3] Returns from producers to the U. S. Geol. Survey.

MARVINE, A. R., Report on the geology of the Middle Park division: Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, pp. 184–192.

Marvine ascended the valley of Blue River from Grand River, but devoted most of his attention to that part of the basin and its bounding ranges lying north of the confluence of Tenmile Creek and Snake River with the Blue, where is now the town of Dillon. He noted the occurrence of a thick series of apparently pre-Cretaceous sedimentary rocks in the vicinity of Hoosier and Breckenridge passes, but appears to have concluded that Archean rocks were exposed over a much larger part of what is now called the Breckenridge district than is actually the case. The geologic map of northern-central Colorado (Sheet XII of the Hayden Atlas) shows extensive areas of Archean on both sides of the Blue near Breckenridge and on both sides of French Gulch from the vicinity of Lincoln to the pass at its head. The basin of the Swan also is represented as being entirely in the Archean ("metamorphic granite").

Marvine concluded that the Cretaceous beds of the Williams Mountains, which lie east of the Blue between Snake and Grand rivers, are faulted down against the Archean rocks lying to the east of them, the throw being estimated at 7,000 feet at least. Southward the fault, according to Marvine, "appears to form the eastern side of the valley of the Blue for some distance, while it may be the northern continuation of some of the great faults that occur in the neighborhood of Mount Lincoln." The distribution of the Dakota sandstone, as shown on the Hayden map, however, negatives the suggestion of any important fault extending from the Williams Mountains past Breckenridge to the vicinity of Mount Lincoln.

EMMONS, S. F., Geology and mining industry of Leadville: Mon. U. S. Geol. Survey, vol. 12, 1886, with atlas.

The region particularly described by Mr. Emmons lies southwest of the Breckenridge district, but his more detailed descriptions are introduced (Chapter II) by a general account of the geology of the Mosquito (or Tenmile) Range and many of the rocks dealt with in his report occur also near Breckenridge. Some familiarity with the Leadville monograph is thus a prerequisite to any thorough study of the Breckenridge area; but it is too extensive a work to summarize here, and the interested reader should consult the original.

CROSS, WHITMAN, The laccolitic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 222–224, 227.

Describes the intrusive porphyries of the Tenmile district, which Cross regards as practically all slight variants of one chemical type, the conspicuously porphyritic variety (Lincoln porphyry) being considered as differing only in texture from others that grade into hornblendic facies, nearly free from quartz. Refers to the Dakota, "probably with a thin layer of upper Jura below it," resting on the Archean in Middle Park, "at the eastern base of the Mosquito Range, opposite the Tenmile district." The porphyries of the Tenmile district are older than the Mosquito fault, which, on the Hayden map, is shown faulting the Triassic and Jurassic but not the Dakota. Cross, however, points out that porphyries similar to those of the Tenmile district cut Cretaceous rocks at Blue River Butte and suggests that the Mosquito fault is probably younger than the Jurassic.

EMMONS, S. F., Tenmile district special folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

Describes the geology and ore deposits of an area of 55 square miles adjacent to Kokomo, a town 10 miles west of Breckenridge. The sedimentary formations recognized are (1) the "Sawatch" quartzite, of Cambrian age, resting on the Archean gneiss, granite, and schist; (2) the Yule limestone, of Silurian age; (3) the Leadville limestone; (4) the "Weber formation;" and (5) the Maroon formation, all three of Carboniferous age; and (6) the "Wyoming" formation of "Juratrias" age.

The Archean rocks constitute a crystalline complex, the granites, gneisses, and schists being traversed by irregular intrusions of pegmatite and cut by eruptive rocks of post-Archean age.

The "Sawatch" quartzite is white and evenly bedded with a fine-grained siliceous conglomerate at its base. The thickness of the formation ranges from 160 to 200 feet. Fossils belonging to a *Dikellocephalus* fauna of Upper Cambrian age have been found in some argillaceous and calcareous shales in the upper part of the formation.

The Yule limestone (not exposed within the area mapped) is characterized as a series of light drab-colored, generally rather thin-bedded limestones, which are in many places magnesian and are everywhere more or less siliceous, in some places passing into calcareous sandstones. Their total thickness ranges from 120 to 160 feet. Conformably overlying the Yule limestone is the so-called Parting quartzite, from 15 to 60 feet thick, provisionally included with the Silurian beds. Near Leadville there is evidence of an unconformity between the "Parting" quartzite and the succeeding formations.

The Leadville limestone (blue limestone) of Mississippian age, is the principal ore-bearing formation of Leadville, Red Cliff, and Aspen. In the Mosquito Range it is a dolomite, bluish gray or black near the top and lighter colored near the base. It has a granular texture and is generally thick bedded. It contains characteristic dark cherty concretions, is fossiliferous near the top, and passes upward into alternating shale and sandstone. The average thickness is about 200 feet, but the formation is not exposed in the Tenmile district.

The "Weber formation" includes a lower calcareous shale member, called in the Leadville monograph the "Weber shales," which is transitional between the Leadville limestone and the main part of the "Weber formation," called the "Weber grits" in the Leadville report. This lower member is assumed to be about 300 feet thick in the Tenmile district and contains Pennsylvanian fossils. The upper member consists of coarse micaceous sandstones or grits, with subordinate beds of shale and dolomitic limestone, the latter being important as containing a large class of the ore deposits of the Tenmile district. The prevailing color is light gray and the thickness of the sandstone member is about 2,500 feet.

The Maroon formation conformably overlies the "Weber formation," which it in many respects resembles. It differs from the "Weber" chiefly in the nonmagnesian character of its included limestone beds and in being generally of a reddish color. The limestones have afforded fossils of upper Pennsylvanian age. The total thickness of the Maroon formation is given as 1,500 feet.

The "Wyoming" formation lies conformably on the Maroon and consists chiefly of sandstones with some intercalated shale, the whole being of a bright brick-red color. The sandstones are composed mainly of Archean débris and in many places are conglomeratic. Limestone is less abundant than in the two preceding formations. The total thickness of the "Wyoming" is said to be 1,500 feet.

The Archean rocks and overlying beds are cut by dioritic porphyries of which three varieties are distinguished on the geologic map, namely, the Lincoln, Elk Mountain, and Quail porphyries. Under Elk Mountain porphyry are included various kinds transitional between the Lincoln and Quail types. The Lincoln type is characterized by large phenocrysts of orthoclase and smaller ones of quartz. It is suggested that the rock is in part a granite porphyry. The Elk Mountain porphyry at the type locality is similar to the Lincoln porphyry but does not contain the large orthoclase phenocrysts. The Quail porphyry is decidedly hornblendic without noticeable megascopic quartz. The prevailing color is dark green. All the porphyries would probably have been classed with quartz monzonite and monzonite had the folio been written a few years later. The porphyries occur principally as intrusive sheets in the sedimentary formations and the number and regularity of these igneous intercalations are striking features in the structure of the district. There are also some bodies of rhyolite in the district that are much younger than the dioritic porphyries.

The sediments and porphyry sheets are gently flexed and are faulted down along the west base of the Mosquito or Tenmile Range by the Mosquito fault which may have been initiated in pre-Cretaceous time.

The ore deposits of the Tenmile district occupy fissures in the sedimentary beds and porphyries or occur as replacement bodies in the limestone beds. The ores are prevailingly pyritic, pyrite and pyrrhotite being accompanied by galena, sphalerite, and silver-bearing sulphides, antimonides, and arsenides. Quartz, calcite, and barite are the ordinary gangue minerals.

The ores were probably deposited shortly after the intrusion of the porphyries and before the uplift of the Mosquito Range by faulting. Thus two periods of faulting are recognized; the first dislocations provided the channels for ore deposition, the second series of faults displaced the ore bodies and effected the Mosquito uplift.

Capps, S. R., and Leffingwell, E. D. K., Pleistocene geology of the Sawatch Range, near Leadville, Colo.: Jour. Geology, vol. 12, 1904, pp. 698–706.

Included in later publication by Capps, listed below.

Westgate, Lewis G., The Twin Lakes glaciated area, Colorado: Jour. Geology, vol. 13, 1905, pp. 285–312.

Describes the glacial geology of a part of the Leadville region. Two epochs of glaciation are recognized and their deposits described. The terrace deposits of the upper Arkansas are ascribed to stream action.

Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: Bull. U. S. Geol. Survey No. 320, 1907.

An advance portion of a complete revision of the Leadville geology. The origin of the glacio-fluvial deposits is discussed at length and the presence of some true lake beds reaffirmed. The genesis of the Leadville ores is reviewed in the light of past criticism and new knowledge, but the authors avowedly leave unanswered as yet some of the most important theoretical questions relating to the source of the ores.

Van Horn, Frank R., A new occurrence of proustite and argentite: Am. Jour. Sci., 4th ser., vol. 25, 1908, pp. 507–508.

Describes and analyzes specimens of proustite and argentite from the California or Bell mine on Glacier Mountain, about 3 miles southwest of Montezuma.

——— Occurrence of proustite and argentite at the California mine, near Montezuma, Colo.: Bull. Geol. Soc. America, vol. 19, 1908, pp. 93–98.

Practically the same as the foregoing paper.

Lakes, Arthur, The general geology of Summit County, Colo.: Min. Sci., March 5, 1908, pp. 243–244.

Brief notes on the general geology, veins, and placers.

Spurr, Josiah E., Garrey, George H., and Ball, Sydney H., Economic geology of the Georgetown quadrangle, together with the Empire district, Colorado [by Spurr and Garrey], with general geology [by Ball]: Prof. Paper U. S. Geol. Survey No. 63, 1908.

A very detailed account of a district only about 10 miles east of the Breckenridge district. The rocks are chiefly pre-Cambrian and are cut by pyritic gold-bearing veins and argentiferous galena-zincblende veins. The gangue of both is largely quartz. The two classes of veins are described as genetically connected with two distinct groups of porphyritic intrusions. The auriferous veins are probably younger than the argentiferous veins. The original ores are believed to have been deposited from water of magmatic origin and to have undergone considerable change and enrichment through the action of cold descending waters. The greater part of the gangue materials were derived from the wall rock.

PATTON, HORACE B., The Montezuma mining district of Summit County, Colo.: First Ann. Rept. Colorado Geol. Survey, for 1908, Denver, 1909, pp. 105–144.

Describes the general geology and divides the Archean rocks into the Idaho Springs formation, consisting chiefly of mica-sillimanite schists, and the "hornblende gneiss series," comprising many varieties of foliated hornblendic rocks. Three kinds of granite are distinguished and a number of intrusive porphyries and aplites are described under the heading "Effusive rocks."[1]

Two distinct vein systems are recognized, one set striking in a general northwest direction and the other striking between northeast and north. Most of the ore bodies are in the northeast-southwest veins. The dip is generally to the northwest and is steep, as a rule. The ores are described as being largely replacements of the country rock along fissures, but some veins have a crustified structure and are fissure fillings. The most abundant gangue material is quartz, but siderite and barite also occur in many veins. The ore minerals comprise proustite, stephanite, argentite, argentiferous galena, sphalerite, and chalcopyrite, of course with pyrite. The chief value of the ores in the past has been in their silver and gold contents. Secondary enrichment, according to Patton, has not been important. The veins are younger than the intrusive porphyries and may be of Tertiary age.

CAPPS, STEPHEN R., JR., Pleistocene geology of the Leadville quadrangle, Colorado: Bull. U. S. Geol. Survey No. 386, 1909.

The glacial deposits described in this bulletin include those of the upper Blue and its tributaries to a point about a mile north of Breckenridge. Two epochs of glaciation are recognized. The older epoch is represented by small residual areas of decomposed morainal material and by the high terrace gravels of the valley of the Arkansas, which are interpreted as fluviatile deposits laid down by streams from the melting ice. The connection of these deposits with an older glacial epoch was long ago pointed out by Emmons (in the Leadville monograph), who, however, regarded the terrace gravels as having been deposited mainly in a lake.

The younger epoch of glaciation has left abundant evidence of ice action in cirques, striations, moraines, and outwash gravels.

The areas near Breckenridge mapped by Capps as "drift of older epoch of glaciation" appear to include in part some of the later morainal material and in part some of the terrace gravels, no distinctly older drift having been detected in this particular locality during the present investigation.

BRADFORD, A. H., and CURTIS, R. P., Dredging at Breckenridge, Colo.: Min. and Sci. Press, Sept. 11, 1909, pp. 361–366.

Useful as an account of technologic practice.

[1] The adjective "effusive" appears to be inadvertently employed throughout the report for intrusive rocks, Patton stating that surface flows are "entirely wanting."

CHAPTER II.

PRE-CAMBRIAN AND SEDIMENTARY ROCKS.

PRE-CAMBRIAN ROCKS.

REGIONAL RELATIONS.

Granites, gneisses, and schists of pre-Cambrian age occupy extensive areas both to the east and to the west of the Breckenridge district (Pl. I, in pocket). To the west they make up most of the Tenmile Range, and have been briefly described by S. F. Emmons in the Tenmile folio under the name "Archean." They extend to the southwest under the Paleozoic sediments of the Leadville district, and emerge to constitute the rocks of the Sawatch Range. To the east the same ancient crystalline terrane is exposed along the Front Range north of Mount Guyot, and in the Georgetown quadrangle has been carefully studied by Ball,[1] who distinguishes the Idaho Springs formation, consisting of biotite-sillimanite schist, biotite schist, and quartz gneiss, all originally sediments, from eight varieties of more or less metamorphosed igneous rock ranging from pegmatite and granite to diorite or dolerite. The Idaho Springs formation has been recognized also in the Montezuma district by Patton,[2] who furthermore divides the rest of the local pre-Cambrian into a "hornblende gneiss series," three different granites, and various rocks occurring as dikes.

In that part of the Breckenridge district studied in preparation for the present report the pre-Cambrian rocks are visible at the surface only in a few small and for the most part outlying areas. The exposed masses, moreover, have been subjected to weathering that dates in part from Paleozoic time and as a rule are covered with soil and vegetation. In view of these conditions, to attempt in this area a subdivision of the pre-Cambrian and a thorough petrographic study of its constituent units would be a task so manifestly unprofitable that it was not undertaken.

LOCAL DISTRIBUTION.

The largest area of pre-Cambrian rocks exposed in the Breckenridge district (Pl. I) is in the northeast corner, at the head of Muggins Gulch. These rocks are known to extend some distance northeast of the area here mapped, and as Keystone Gulch,[3] 8 miles northeast of Breckenridge, is in pre-Cambrian rocks, this terrane is probably continuously exposed from the head of Muggins Gulch to Montezuma and thence over the Continental Divide into the Georgetown, Idaho Springs, and Central City regions.

Other areas of pre-Cambrian rocks are exposed along the western border of the district. These represent parts, slightly modified, of the old erosion surface upon which the Dakota formation was here deposited and they join farther west with the great pre-Cambrian mass of the Tenmile Range. Still another small but interesting exposure of pre-Cambrian rocks is that in the upper part of Illinois Gulch, in the vicinity of the Laurium and Mountain Pride mines, where the sedimentary rocks have been eroded from the crown of a short irregular anticlinal fold, thereby exposing the crystalline complex upon which they were originally laid down.

[1] Ball, S. H., Prof. Paper U. S. Geol. Survey No. 63, 1908.
[2] Patton, H. B., The Montezuma mining district of Summit County, Colo.: First Ann. Rept. Colorado Geol. Survey, for 1908, 1909, pp. 105-144.
[3] Called Buffalo Gulch on the Hayden map, Keystone Gulch there being the next one west.

PETROGRAPHY.

The most abundant variety of pre-Cambrian rock in the Breckenridge district is a gray fissile micaceous schist composed essentially of quartz, biotite, and muscovite, the last in the fine-leaved form known as sericite. This is probably the equivalent of the Idaho Springs formation of the Georgetown and Montezuma districts. Another fine-grained thinly foliated rock prevalent about the head of the Blue and elsewhere in the Tenmile Range, as well as near the Swandyke, at the head of the Middle Swan, east of Breckenridge, is less fissile than the rock just mentioned and has a gneissic rather than a schistose structure. The microscope shows this rock to consist of quartz, biotite, muscovite, microcline, and a little plagioclase.

At the mouth of North Barton Gulch, 2½ miles north of Breckenridge, is a dark biotitic gneiss, a little coarser in texture than those just described, which is a foliated granite approaching quartz monzonite in composition. Another fine-grained, beautifully foliated, dark-gray gneiss, prevalent about the head of St. Johns Gulch between Breckenridge and Montezuma, contains hornblende as its principal dark constituent and is a quartz diorite gneiss.

All the fine-grained schists and gneisses are intricately and irregularly intruded by various kinds of granitic and pegmatitic rocks. Within that part of the district specially studied the most abundant pre-Cambrian intrusive rock is a medium-grained (about 5 millimeters) reddish granite, of which the conspicuous mineral constituents are flesh-colored feldspar, quartz, and a subordinate quantity of muscovite. The microscope shows that the feldspar includes orthoclase and microcline, both generally microperthitic. Other intrusive rocks, noted particularly at the head of the Blue and at Swandyke, are nearly white pegmatites consisting of orthoclase, microcline, quartz, and muscovite with magnetite locally abundant in small irregular bunches. The pegmatites vary in composition from those with little quartz to those that are chiefly quartz and muscovite.

Thorough study of a large well-exposed body of the pre-Cambrian rocks, such as that forming the mass of the Tenmile Range, would doubtless discover many more varieties of gneiss, schist, and pegmatite than those here mentioned. The brief descriptions given, however, will suffice to indicate in a general way the character of the old foundation upon which the younger sedimentary rocks of the Breckenridge district rest

STRATIFIED ROCKS.

GENERAL STRATIGRAPHY OF THE REGION.

The part of central Colorado that is adjacent to the Breckenridge district exhibits a rather full and unusually uniform succession of beds from the Cambrian to the Cretaceous. Tertiary strata also, notably the famous insect-bearing lake beds near Florissant, occur in South Park, 50 miles southeast of Breckenridge, but these are local deposits that never extended into the area with which this report deals.

To attempt here any extensive treatment of the stratigraphy of central Colorado would be inappropriate; it is sufficient to present such salient facts as have direct bearing on the problems of the Breckenridge district. G. H. Girty, in his exhaustive monograph on the Carboniferous of Colorado,[1] has summarized and fully discussed the literature, not only of the Carboniferous, but virtually of the whole Paleozoic of the State. To his work those who wish to pursue the subject further may be referred.

The Breckenridge region marches with the Robinson or Tenmile district to the west and with the Leadville district to the southwest. Fortunately the stratigraphy of these two districts has been carefully studied and the results are available for comparison. The stratigraphic column at Aspen, 45 miles west-southwest of Breckenridge, has also been accurately described and less satisfactory data have been recorded for Red Cliff, 20 miles northwest of Breckenridge. The essential stratigraphic results of these investigations are summarized in tabular form on the insert facing this page. The column in the table under "Red Cliff" involves some interpretation of Tilden's section, which in its actual published form is as follows:

[1] Prof. Paper U. S. Geol. Survey No. 16, 1903.

System.	Series.	Leadville. Emmons, S. F., Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886.	Tenmile. Emmons, S. F., Tenmile district special folio, No. 48, Geol. Atlas U. S., U. S. Geol. Survey, 1898.	Aspen. Spurr, J. E., Geology of the Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898.	Red Cliff. Tilden, G. C., Mining notes from Eagle County: Bienn. Rept. State School Mines, Golden, Colo., 1886, p. 129.[a]	Breckenridge.
Cretaceous.	Upper Cretaceous.			*Niobrara.* Gray limestone. Grades up into Montana formation. 100 feet.		*Upper Cretaceous shale.* Dark shales with a few thin layers of limestone and of gray quartzite. Contains Benton, Niobrara, and possibly Montana fossils. 3,500–5,500 (?) feet.
				Benton. Black calcareous shales. 350 feet. Colorado group.		
				Dakota. Massive white sandstone with local variations. 250 feet.		*Dakota sandstone.* Buff sandstone passing locally into white quartzite, with more or less gray shale. May include some Lower Cretaceous and some Morrison formation (Lower Cretaceous or Jurassic). 200–300 feet.
Jurassic.		Absent.	Absent.	*Gunnison formation.*[b] Gray or yellow sandstone, often calcareous, overlain by reddish, grayish, or variegated shaly sandstones. 300 feet. Unconformity.		Not definitely recognized. Some Morrison formation (Jurassic?) may be included with the rocks mapped as Dakota.
Triassic (?).		Absent.	*Wyoming formation.* Brick-red sandstones with some red shale and local coarse conglomerate. 1,500 feet.	*Triassic.* Red sandstones; light red below, darker above. 2,600 feet.		"*Wyoming*" formation. Brilliant red sandstones and shales. Probably equivalent or nearly so to the Lykins formation of the Boulder district, Colo. 0–1,000 feet.
Carboniferous.	Pennsylvanian.	Upper Coal Measures.	*Maroon formation.* Coarse gray and red sandstones with associated conglomerates and limestone. 1,500 feet.	*Maroon formation.* Dark red grits and thin shaly limestone. Pass gradually into foregoing. 4,000 feet.		Absent.
		Weber grits.	*Weber formation.* Mainly coarse gray sandstones and grits (Weber grits, 2,500 feet) with some carbonaceous shales near base and a few thin beds of dolomitic limestone (Weber shales, 300 feet), 2,800 feet.	*Weber formation.* Thin-bedded, carbonaceous limestone and calcareous shales. 1,000 feet.	Carboniferous limestone. 1,000 feet.	Absent.
		Weber shales.				
	Mississippian.	*Blue limestone.* Compact, heavy-bedded, dark blue dolomitic limestone. Black chert, 200 feet. Concretions near top. Unconformity.	*Leadville limestone* (not exposed). 200 feet.	*Leadville limestone.* Thick-bedded gray-blue dolomite grading upward into gray-blue limestone. 350 feet.	Black siliceous limestone. 300 feet. Blue dolomitic limestone. 250 feet.	Absent.
Devonian (?)		*Parting quartzite* (Lower Silurian in Leadville report). White quartzite. 40 feet.	*Parting quartzites* (not exposed). 15–16 feet.	*Parting quartzite.* Thin-bedded quartzite and dolomite. 60 feet.	?	Absent.
Ordovician or "Lower Silurian."		*White limestone.* Light-gray, siliceous dolomitic limestone, with white chert concretions. 160 feet.	*Yule limestone* (not exposed). 120–160 feet.	*Yule formation.* Hard, compact gray-blue to yellow-brown dolomites. 250–400 feet.	?	Absent.
Cambrian.		*Lower quartzite.* White quartzite passing upward into calcareous and argillaceous shales. 150–200 feet.	*Sawatch quartzite.* White and generally thin-bedded. 160–200 feet.	*Sawatch formation.* White quartzite conglomeratic at base, grading upward into sandy dolomitic, and occasionally glauconitic varieties. 200–400 feet.	Conglomeratic quartzite. 8 feet. "Silurian white quartzite." 5 feet. Fine-grained sandstone. 100 feet. "Cambrian white quartzite." 125 feet.	Absent.

[a] As interpreted by Girty, Prof. Paper U. S. Geol. Survey No. 16, p. 57.
[b] On page 39 of the Aspen monograph the Gunnison formation is placed under the general heading "Triassic." This, however, is apparently a mere oversight in arrangement.

Gneiss.	Feet.
Cambrian white quartzite	125
Fine-grained sandstone	100
Silurian white quartzite	5
Conglomerated quartzite	80
Blue dolomitic limestone	250
Black siliceous limestone	300
Carboniferous limestone	1,000
Leadville quartz porphyry	200

Concerning this Girty remarks:

Probably the four lower members of the section, aggregating 238 feet, should be considered as representing the Sawatch quartzite * * *. The next two divisions, amounting to 550 feet, have the position and character of the Leadville limestone. If they be taken to represent the Leadville, however, no equivalent of the Yule limestone and Parting quartzite can be found. It is clear from Emmons's remarks that these formations are not normal at this locality. If a portion of the blue dolomitic limestone belongs to the Yule, the Parting quartzite would still be missing. Tilden seems to suggest that the third member of the section, which he designates the Silurian quartzite, is the Parting formation. If this is indeed the case the Yule limestone as such is absent. The next bed, consisting of 1,000 feet of limestone, would appear to represent the Weber formation of the Aspen district and the Weber shale of the Tenmile district.

The ages of some of the formations listed in the table have been satisfactorily determined on the evidence of fossils, this being generally true of the beds from the Maroon formation downward, with the exception of the "Parting" quartzite; but the age and correlation of the series of red beds lying between the Maroon and Dakota formations are still imperfectly known. Thus the "Wyoming" formation of the table has never been shown to correspond accurately to the formation in the Denver Basin to which the name was originally applied, although most geologists who have studied the beds both in central Colorado and on the east flank of the Front Range agree in considering them practically equivalent.[1] If this supposition is correct, then of course the Fountain formation of the east slope is equivalent, in part at least, to the Maroon formation west of the Front Range and similarly the Morrison formation, overlying the "Wyoming" in the type locality of the latter, is equivalent to the upper part of the Gunnison formation or to the McElmo formation farther west. The bright-red beds of the "Wyoming" have generally been considered Triassic, but the possibility of their being wholly or partly Permian has never been entirely eliminated. Emmons[2] records that Lakes found, just east of Fairplay, in beds above what was later named the Maroon formation, plant remains determined by Lesquereux as Permian, and fossil insects determined by A. Hyatt as Triassic. Darton,[3] also, presents evidence indicative of Permian age for at least the lower third of the Upper Wyoming of Eldridge in the Denver region and Cross and Howe[4] assign "the entire red-bed sections of the Denver region and southward, at least to the Canyon City embayment, to the Paleozoic." The age of the Morrison formation, according to Stanton,[5] still awaits accurate determination. Whether it is Jurassic or Cretaceous (Comanche) is unknown.

HOOSIER PASS SECTION.

One of the most instructive sections in the region, preparatory to a study of the stratigraphy of the Breckenridge district, is that across Hoosier Pass (see Pl. III, p. 16), which has been described in part by S. F. Emmons.[6] Lying 8 miles due south of Breckenridge, this section affords an opportunity of examining the entire stratigraphic sequence from the pre-Cambrian of North Star Mountain (Star Mountain or North Peak on some maps) on the west to the black Upper Cretaceous shale at Breckenridge Pass or Boreas on the east. The general strike of these beds ranges from north to N. 25° W.; the dip, except at one place in Hoosier Pass,

[1] See Girty, G. H., op. cit., p. 190.
[2] Geology and mining industry of Leadville: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 71.
[3] Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Bull. Geol. Soc. America, vol. 15, 1904, p. 416; Geology and underground water resources of the central Great Plains: Prof. Paper U. S. Geol. Survey No. 32, 1905, pp. 81-87.
[4] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, p. 492.
[5] Stanton, T. W., The Morrison formation and its relations with the Comanche series and the Dakota formation: Jour. Geology, vol. 13, 1905, p. 668.
[6] Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 100-104, atlas sheets VI and VIII.

where, as Emmons shows, there is a local syncline, is uniformly east at angles ranging from 20° to 45°, the average or general dip being about 35°. The distance nearly across the general strike of the beds from the base of the section west of Hoosier Pass to Boreas is approximately 8 miles. As Emmons has remarked,[1] the section does not lend itself to accurate measurements of total thickness. The best exposures are along the winding Continental Divide, which in places makes small angles with the strike. Even on this ridge the exposures are not continuous and it is impossible to be sure that no duplication has been effected by faulting. The sediments, moreover, are intruded by numerous bodies of porphyry, both as sheets and dikes, and the extent to which these intrusions have increased the apparent thickness of the sedimentary rocks can be determined only when the geology on both sides of the line of section has been accurately mapped. Notwithstanding these deficiencies, the section is an excellent one along which to study the varied lithology of the successive formations.

North Star Mountain, upon which the base of the section rests west of Hoosier Pass, is a narrow spur of gneiss and granite jutting eastward from the crest of the Tenmile Range between Quandary Peak on the north and Mount Lincoln on the south. At the east end of its nearly level crest, at an elevation of 13,400 feet, the spur is capped by Cambrian quartzite (Sawatch quartzite of Emmons) dipping gently eastward. This is about 100 feet thick and, at the few places where the contact with the pre-Cambrian was clearly examined, is not accompanied by any basal conglomerate. The weathered rock is nearly white, but specimens from shafts are greenish gray, the green tint being due to a little chlorite in the quartz that cements the original sand grains.

Overlying the quartzite on the crest of the spur is an isolated mass of Cambrian limestone (Yule limestone of Emmons) not shown in Emmons's map or section. East of this limestone the slope leading down to Hoosier Pass for a distance of nearly 4,000 feet is virtually a dip slope on the quartzite from which the limestone has been eroded. Then the limestone reappears, dipping 30° E. Emmons's section shows both the Yule and Leadville limestones with a total thickness of about 400 feet and he describes the "Blue" or Leadville limestone as "a dark iron-stained dolomite, weathering black." In a necessarily hasty trip over this part of the section in 1908, I failed to find any exposure of the "Parting" quartzite or to distinguish any essential difference between the upper and lower beds of limestone. The prevailing variety is a sandy dolomite, pinkish gray on fresh fracture, but weathering buff or rusty brown. Much of it is banded, and on weathered surfaces the bands stand out as narrow, parallel rust-brown ridges of porous material consisting mainly of silica and limonite. Possibly one thoroughly familiar with the Leadville section might be able to distinguish the two limestones west of Hoosier Pass; but in the absence of such special knowledge most observers would probably see at this locality little suggestive of a division of the limestone series.

Overlying the limestone are thin-bedded gray and buff arkosic grits and conglomerates with intercalated beds of dark micaceous shale in which Emmons found "casts of *Zaphrentis* and corals."[2] These are the "Weber shales" of the Leadville monograph. At this locality, however, arkosic grits are fully as abundant as shales and there is certainly no distinctively shaly division at the base of the "Weber formation." The prevalent beds of the "Weber," all the way down the slope to Hoosier Pass and up to an elevation of about 12,800 feet on the slope east of the pass, are gray, very micaceous, quartzose grits. Some are fine grained and shaly, looking almost like mica schists. Others are conglomeratic with pebbles of well-rounded white quartz. Some beds are mostly quartz and muscovite; others are granitic arkoses, contain abundant microcline with some orthoclase, and weather to a soil that, were the arkosic character of the terrane unknown, would strongly suggest underlying granite. No limestone was noted in the "Weber" of this section except one thin bed near the top of the formation. The whole thus contrasts strongly with the calcareous "Weber formation" of the Aspen district and was evidently deposited in shallow water close to a pre-Cambrian land mass that furnished the

[1] Op. cit., p. 101.

[2] Idem, p. 100.

abundant quartz sand and flakes of muscovite. Emmons's section assigns a thickness of 2,000 feet to the "Weber" at Hoosier Pass, but this is avowedly an estimate, not a measurement.

Above the "Weber" in Hoosier Ridge, east of the pass, come the "Upper Coal Measures" of the Leadville report, or the beds now known as the Maroon formation. Lithologically these resemble the "Weber" in all but color. The "Weber formation" is invariably gray; the Maroon formation is generally dark red, but in detail shows many alternations of gray and red or variegated beds. The Maroon appears to be perfectly conformable with the "Weber," and there is nothing in this section to mark a definite boundary between the "Weber" and the Maroon unless it is the appearance of the first reddish bed. Emmons refers to "a bed of dark-blue limestone about a hundred feet in thickness" in the lower part of the Maroon, from which he obtained a number of Pennsylvanian fossils.[1] What is supposed to be this same limestone was crossed in my own traverse of 1908 at an elevation about 75 feet higher than the lowest of the dark red beds. As locally exposed, however, it did not appear to be over 15 feet thick and yielded no fossils. Another thin bed of similar limestone outcrops in the "Weber" about 75 feet below the lowest red bed.

Two miles east of Hoosier Pass the Continental Divide turns north along the crest of Hoosier Ridge toward Red Peak, the line of traverse here being nearly parallel with the strike for about 2 miles. This turn marks the east end of Emmons's section, the crest of the ridge being here formed by a sheet of porphyry.

Near Red Peak, which apparently consists mainly of eastward-dipping Maroon beds capped by a thick sheet of porphyry, the divide turns northeast, south of Horseshoe Basin, toward Breckenridge Pass. Here the traverse showed a gradual transition from the alternating gray and dark-red beds of the Maroon formation into the brilliant brick-red sediments of the "Wyoming" formation, consisting of generally rather thin bedded micaceous shales, flaggy ripple-marked sandstones, and cross-bedded conglomerates, all bright red except where metamorphosed by porphyry intrusions into greenish-gray epidotized rocks. The red pigment of these sediments is mainly in the more or less calcareous cement that holds together the grains of quartz and feldspar and the very abundant muscovite flakes

The pebbles in the "Wyoming" are chiefly quartz, are not well rounded, and are rather sporadically distributed through their sandy matrix. In fact, the coarsest beds are more aptly described as pebbly grits or pebbly sandstones than as conglomerates. With the quartz pebbles in some beds are pebbles of various pre-Cambrian crystalline rocks. Thin beds of gray limestone are fairly common in the "Wyoming." A characteristic feature of the red beds, both in this formation and in the Maroon, is the presence of greenish spots due to local bleaching of the iron-oxide coloring material by natural reducing agents.

The thickness of the "Wyoming" as exposed between Red Peak and Boreas can not be accurately estimated from a single traverse, owing to the complications introduced by the porphyry intrusions and to some uncertainty as to the exact position of the base of the "Wyoming" or the top of the Maroon. The width of the belt nearly at right angles with the general strike is about 2 miles. This, with an average dip of 35°, would give a thickness of about 6,000 feet. From this something must be subtracted for the included porphyry sheets, which, however, in this part of the section are probably less than 1,000 feet in aggregate thickness. There is little suggestion of important faulting, and it appears reasonable to conclude that 5,000 feet is a fair estimate for the total thickness of the "Wyoming" in this section. Emmons gives the maximum thickness in the Tenmile district at 1,500 feet, but the formation has there suffered some loss by erosion.

If the Morrison formation is represented in the Hoosier Pass section it has not been distinguished from the "Wyoming," which about three-quarters of a mile west of Boreas appears to be conformably overlain by what in this region has generally been considered, since the days of the Hayden Survey, as the Dakota formation. This is well exposed on a little knoll on the ridge, striking N. 16° W. and dipping 43° E. At the base is a bed about 6 feet thick of

[1] Op. cit., p. 103.

coarse light-buff pebbly sandstone. The pebbles, which are abundant, are of white quartz and are mostly under half an inch in diameter, but range from the smaller sizes up to those 2 inches across. This pebbly bed is succeeded by buff sandstones in beds of similar moderate thickness, the whole constituting a basal arenaceous member about 50 feet thick. Above this comes a middle thin-bedded member about 100 feet thick consisting of thin argillaceous and arenaceous limestones with some pebbly grits and a little dark shale. These weather pink or light red as a whole, but are not so red as the "Wyoming" beds. Some porphyry is irregularly intruded into these thin beds west of Boreas. Overlying this middle member is an upper sandy division consisting of 50 feet of thick-bedded, even-grained buff sandstones. This is the most conspicuous member of the Dakota and to the north changes to a hard white quartzite that resists erosion and forms the summits of many of the hills near Breckenridge. Although the Dakota formation as a whole is persistent over vast areas, it is apparently variable in the character and succession of its beds. In some places, as in the vicinity of Dillon, north of Breckenridge, the Dakota shows three prominent sandstone members, and other variations will appear when the rocks of the Breckenridge district are described in detail.

The beds overlying the Dakota and occupying Breckenridge Pass are very poorly exposed. In some places a little fine-grained gray sandstone is visible, and a short distance above the Dakota are three or four beds of gray limestone, up to 4 feet in thickness, interbedded with the sandstone. But probably most of the rock under the grass-covered slopes of the pass is a dark fissile shale, which will be described later from other and better exposures than are afforded by this particular section. This shale is intruded just east of Boreas by the great porphyry sheet of Bald Mountain, and there is no way, either on the line of the Hoosier Pass section or elsewhere in the vicinity of Breckenridge, of ascertaining its total original thickness. On Trout Creek, 4 miles east of Fairplay and 13 miles south of Boreas, Peale's section [1] indicates the possibility of these shales being over 1,000 feet thick. As will be later shown, the black and gray shales of this region carry fossils of Benton, Niobrara, and possibly also of Montana age, and, as it is impracticable to divide these rocks into distinct formations corresponding to these chronologic divisions of the Cretaceous, the whole will be referred to as the Upper Cretaceous shale.

It will appear from the foregoing notes on the Hoosier Pass section that in the area from 6 to 8 miles south of Breckenridge the Dakota is separated from the pre-Cambrian by several thousand, perhaps 10,000, feet of sediments whose beds strike in a general way toward Breckenridge. Two miles north of that town the Dakota, on the other hand, rests directly upon the pre-Cambrian. Thus within a distance of 10 miles the entire stratigraphic section of the Leadville and Tenmile districts has disappeared. This fact was indicated in a general way on the Hayden map of Colorado, which, however, was probably nowhere more inaccurate than in the part pertaining to the Breckenridge and Leadville region. Some explanation of this transgression of the Dakota upon the pre-Cambrian will be attempted in a later chapter.

Although there is no apparent unconformity in the Hoosier Pass section, it should be remembered that Eldridge,[2] in the Crested Butte region, found the Gunnison formation resting unconformably on the Maroon formation and that Cross and Howe,[3] at Ouray and elsewhere, have recognized another important unconformity at the base of the Triassic Dolores formation.

SEDIMENTARY FORMATIONS OF THE BRECKENRIDGE DISTRICT.

FORMATIONS REPRESENTED.

The sedimentary formations occurring in the mapped part of the Breckenridge district (Pl. I, in pocket) are the "Wyoming" formation, the Dakota sandstone, and the Upper Cretaceous shale. As is apparent from the geologic map, the smallness of the area and the great

[1] Seventh Ann. Rept. U. S. Geog. and Geol. Survey Terr., for 1873, 1874, p. 218.

[2] Eldridge, G. H., Anthracite-Crested Butte folio (No. 9), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

[3] Cross, Whitman, and Howe, Ernest, Red beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, pp. 447-498. Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, 1907, pp. 634-679.

local disturbance of the beds by the intrusion of many irregular masses of porphyry render the Breckenridge district a field that is exceptionally unfavorable for the study of the sedimentary rocks and not likely to add greatly to existing knowledge of the regional stratigraphy except as regards the interesting problem raised by the disappearance of the Paleozoic beds between Breckenridge and Hoosier Pass. Even this problem might be much more readily and convincingly solved could accurate topographic and geologic mapping have been carried southward to the head of the Blue.

"WYOMING" FORMATION.

NAME.

The name "Wyoming" might not have been applied in this report to the generally bright-red beds underlying the Dakota had not Emmons previously used it in the adjoining Tenmile district. The correlation of the red beds of the Tenmile district with the "Wyoming" of the Denver Basin having been authoritatively made, however, it is better to accept it than to introduce any change into the nomenclature, particularly as the detailed study of the small Breckenridge area, in which the formation is not fully and typically developed, is a wholly inadequate foundation upon which to base any essential modification of current terminology. The "Wyoming" formation of the Breckenridge district is probably the stratigraphic equivalent of the Lykins formation of the Boulder district, Colorado. As Cross and Howe [1] have remarked, it is premature to attempt direct correlation of the Dolores (Triassic) and Cutler (Permian) formations of southwestern Colorado, as such, with the stratigraphic units of central and northern Colorado.

DISTRIBUTION.

The "Wyoming" formation is displayed mainly in the southern part of the district, the only beds north of Breckenridge referable to this formation being some that are exposed in placer pits and tunnels along the east side of the Blue, between the mouth of French Creek and Braddocks station. The largest area shown on Plate I (in pocket) is that adjacent to the Laurium and Mountain Pride mines, extending from the head of Australia Gulch on the north to a point a short distance south of the mapped area. This body of sediments occupies the greater part of the basin drained through Illinois Gulch and may be conveniently referred to as the Illinois Gulch area.

Not entirely separate from this area is another, which is drained in large part by Indiana Gulch and, south of the district proper, by Pennsylvania Gulch. Part of this area is crossed by the railway between Boreas and Bacon, the numerous cuts affording excellent exposures of the vivid red grits. It is the rock at Farnham station, between Bacon and Boreas, and of the Warrior's Mark mine, south of that station. Characteristic exposures may be examined also along the wagon road up Indiana Gulch to Boreas and all the way up Pennsylvania Gulch to the fine amphitheater at its head known as Horseshoe Basin. The same formation also probably underlies a large part of the morainal material and glacial silt south of Breckenridge.

THICKNESS.

The thickness of the "Wyoming" formation at the south edge of the Breckenridge area, near Bacon, can not be accurately measured, but is probably at least 1,000 feet. It is estimated that a little farther north, east of the Laurium mine, from 600 to 700 feet of these beds intervenes between the pre-Cambrian and the Dakota. Thence the formation thins rapidly to the north. Along the west base of Gibson Hill the beds are so poorly exposed that no reliable estimate of their thickness is possible, but the maximum can scarcely exceed 400 feet and, inasmuch as the Dakota in the neighborhood of the three Barton gulches rests on the pre-Cambrian, is probably much less than that. The apparent thickness here is perhaps due to faulting.

LITHOLOGY.

In Indiana Gulch the "Wyoming" beds are uniformly bright red and are for the most part rather coarse quartzose grits, many of them pebbly, grading upward and downward into flaggy

[1] Red beds of southwestern Colorado and their correlation: Bull. Geol. Soc. America, vol. 16, 1905, p. 488.

micaceous sandstones interbedded with sandy, micaceous red shales. The coarser material in some places shows cross-bedding, and many of the shale layers are ripple marked. The imperfectly rounded pebbles are as a rule of white vein quartz, although some beds contain fragments of crystalline pre-Cambrian rock. The pebbles occur as ill-defined bands or streaks in the laminated grits and not as definite persistent beds of conglomerate. The different beds vary in the character of their cementing material. Some effervesce freely with acid, showing that the cement is mainly calcite. Others show little or no effervescence and are probably rendered coherent by films of quartz or oxide of iron.

A few thin lenticular beds of compact gray limestone occur in the grits and shales. One of these, about 1 foot thick, is exposed on the slope 2,200 feet east of Bacon. At least two similar beds outcrop on the north side of Illinois Gulch, west of the pre-Cambrian area.

As the red beds are followed northward to the vicinity of the pre-Cambrian area in Illinois Gulch they change in character. The intensely red color so characteristic of the formation farther south becomes less noticeable and the sediments assume a variegated aspect. Many of the beds, especially the shaly ones, retain their bright hue but others are gray, buff, or maroon. In short, the formation as it approaches the pre-Cambrian exhibits features strongly suggestive of the Maroon and "Weber" formations. A diamond-drill hole bored some years ago at the Mountain Pride mine should supply much interesting information as to the character and thickness of the formation, but no record of the material passed through has been found. The pieces of core scattered about the ground at the abandoned mine consist of arkosic grits with much pink orthoclase or microcline and abundant muscovite. Some are coarse and pebbly; others are fine grained and in consequence of the original settling of the mica flakes on their flat sides can be split with ease in planes parallel with the bedding. A large part of the core is gray, but some of the fine flaggy micaceous sandstones are striped with dull maroon and some finely micaceous calcareous shale is light pinkish red. Shale identical with the last-named variety occurs in the Gold Bell tunnel, 1 mile a little east of north from the Mountain Pride mine, and in the French Creek tunnel, half a mile southwest of Lincoln. In both of these tunnels this pink or red shale occurs in the upper part of the formation and is underlain by arkosic grits. These grits, varyingly pebbly, as exposed in superficial openings between the Gold Bell tunnel and the pre-Cambrian inlier are mainly gray but include also some buff, maroon, and red beds. In the French Creek tunnel, which cuts the formation about 500 feet below the surface and under the Bald Mountain sheet of diorite porphyry, the grits are all gray and contain finely disseminated pyrite. Some of the coarser bands in the arkosic material contain angular fragments of fresh feldspar up to 1½ inches in length, muscovite flakes half an inch broad, and quartz pebbles up to 2 inches in diameter.

It thus appears that the sediments between the pre-Cambrian and the Dakota in the Breckenridge district are not distinctly of "Wyoming" type but are in part identical in lithologic character with beds found in the Maroon and "Weber" formations.

CAUSE OF THE RED COLOR.

Study of thin sections of the red sandstones shows that their color is due to thin films of ferric oxide coating the surfaces of the detrital grains and not to any original redness of the constituent particles. Hard, dense grains, like those of quartz or fresh feldspar, have merely a skin of red pigment. Porous, decomposed, or lamellar minerals have had the iron oxide deposited within them in microscopic pores or along planes of parting. Some of the red-coated grains are surrounded by calcite, and it is difficult to avoid the conclusion that the sediments were red before they were fully cemented. On the other hand, the coloring matter clearly was not introduced until after attrition of the grains had ended and they had come to rest in the beds where they now lie.

The cause of the red color of some sandstones and shales has been investigated by many. Among the later contributions to the subject is the work of G. B. Richardson,[1] who concluded that the dominant factor was the derivation of the beds from a residual red soil, although the

[1] The upper red beds of the Black Hills: Jour. Geology, vol. 11, 1903, pp. 381-393.

dehydrating effect of deposition in salt water, as suggested by W. Spring, is given some weight. More recently Joseph Barrell[1] has summarized in part the literature on this problem and, in general agreement with W. O. Crosby, holds that the redness is normally assumed on consolidation by any sediment containing an appreciable quantity of ferric hydrate, through dehydration favored by several factors, among which he mentions time, pressure, high temperature, and alternating wetness and dryness but does not refer to the probably important factor of salinity.

The red color of the "Wyoming" formation near Breckenridge can not be wholly the effect of atmospheric agencies on the beds as now exposed. The red beds are just as ruddy in railway cuts and in many outlying prospect shafts as at the surface. The deposition of interstitial calcite over the red films also points to the existence of the color prior to the present cycle of weathering. Moreover, Mr. N. H. Darton informs me that east of the Rocky Mountains deep wells in the plains, penetrating the red beds far from their outcrop, show that the color persists far below the present reach of weathering.

On the other hand, some mine workings show a change from red sediments to gray, and Emmons,[2] in describing the Maroon formation in the Tenmile district, states that in depth, as shown in underground workings, the red color is generally replaced by greenish gray, implying that the red hue is due to weathering of the present beds. The Breckenridge district is not a favorable one in which to pursue exhaustively the study of the colors of sedimentary rocks, but such evidence as is available indicates that the color of the red beds is not due to original redness of the unconsolidated sediments and is only in small part due to recent weathering of exposed beds. The ferric oxide pigment may locally be reduced by organic or sulphide solutions. Where pyrite has formed in the rocks, as in the French Creek tunnel, the red color has been obliterated, and inasmuch as disseminated pyrite is abundant in the vicinity of most ore bodies in these beds, it is probable that the change of color noted in the Tenmile district by Emmons, and to some extent observable in the Breckenridge district, does not mean that the rocks deep underground have never been red, but does show the bleaching effect of the formation of pyrite. It is doubtful whether there is any depth at which the strongly colored "Wyoming" beds change generally to gray independently of the presence of pyrite.

CORRELATION.

No fossils have been found in the "Wyoming" formation of the Breckenridge area. The lithologic character of the beds raises the question whether they should be regarded as representing the thin edges of the "Weber," Maroon, and "Wyoming" formations, or whether they belong solely to the last, as is indicated by their general strike. It is difficult, however, in view of the thickness of the "Wyoming" in the apparently conformable Hoosier Pass section, to imagine conditions under which any deposits of "Weber" or Maroon age could have been laid down in the Breckenridge district. That area was probably land at the time these two formations accumulated and supplied part of the detritus of which they are composed. All three formations are clearly of shallow-water origin and were laid down at no great distance from shore. As the land slowly sank sedimentation kept pace with the movement, and the near-shore or littoral conditions under which the base of the "Weber" first overlapped the pre-Cambrian were gradually carried upward in the chronologic scale until they reached "Wyoming" (Triassic?) time. In any sedimentary basin gradually filled by long-continued subsidence of the land a vertical section, such as is given by a deep bore hole made at a point far out from the later shore line of the basin, will normally show a certain definite sequence of beds, perhaps readily divisible into many formations belonging to different geologic periods. Borings made successively nearer to the edge of the basin might be expected to show some of the formations disappearing, becoming coarser, merging with others above or below, and, in general, showing increasing irregularity in consequence of local variations in currents and sediments close to the shore line. Finally, close to the edge, or latest shore, all the older formations will have disappeared, and perhaps the coarse shingle last formed by the waves closely

[1] Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, 1908, pp. 285-294.
[2] Tenmile district special folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898, p. 2.

resembles and is actually continuous with the much older basal conglomerate found at the bottom of the basin in the deepest boring. The hypothetical conditions thus outlined are, it is believed, applicable in a general way to the explanation of the lithologic change in the "Wyoming" formation as it thins out northward and particularly to the fact that, where deposited directly on the pre-Cambrian, its basal portion resembles the grits and conglomerates of the much older "Weber formation."

The Hayden geologic map of north-central Colorado shows a strip of "Jurassic (?), variegated beds, etc.," extending from Hamilton through Breckenridge Pass to French Creek and lying between the "Triassic" red beds and the Dakota. A. C. Peale,[1] however, who studied the geology of the South Park division, describes the red beds of Tarryall Creek, a short distance above Hamilton, as Triassic, and mentions the Dakota ("Cretaceous No. 1") as directly overlying them. In his section No. 9, made from Platte River eastward to Trout Creek, about 5 miles north of Fairplay, Peale, traveling east and from lower to higher beds, gives the following:

	Feet.
52. Space, the valley of Crooked Creek. On the east side of the valley we have the massive red sandstones (Triassic ?) with all the characteristics of the same beds east of the foothills, and on Trout Creek west of them. It is probable they extend down to bed 51. Their softness has allowed them to be worn down, and they have been covered with débris. Total thickness	1,300-1,500
53. Coarse pink sandstones	25
53. Fine-grained rose-colored sandstones	5
These two beds are the upper part of the red beds.	
54. Rather coarse calcareous sandstones, shales mottled red and gray	5
55. Space, probably filled with continuation of 54, grading into the next bed	30
56. Gray compact limestone. This limestone has cross cleavage, and becomes harder as we go up	10
57. Hard fine-grained limestone, light gray	15
58. Space, probably filled with limestones and shales	75
59. Outcrop green shales	10
60. Space, filled with shales and sandstones	60
61. Rusty yellow sandstone	5

In the foregoing, which is a small part only of the full section, the beds numbered from 54 to 60, inclusive, aggregating 205 feet in thickness, correspond to the variegated Jurassic beds of the Hayden Survey and perhaps to the Morrison formation of later writers. No. 61 in the foregoing section Peale regarded as the basal bed of the Dakota and No. 53 as the upper bed of the Hayden Triassic or what has since been named the "Wyoming" formation.

What is now known as the Breckenridge district appears to have been between the area studied by Marvine on the north and that investigated by Peale on the south, and the distribution of the rocks near Breckenridge as represented on the Hayden map was evidently more the result of inference than of observation. The strip of "Juratrias" extending through to French Creek was perhaps surmised mainly from Peale's section, quoted in part on this page. In view of the absence of fossils, the poor exposures, and the disturbing effect of igneous intrusions in the Breckenridge area it is not safe to assert that beds equivalent to the Morrison formation are wholly lacking. It has not been found possible, however, to distinguish and map any formation between the Dakota and the "Wyoming."

DAKOTA SANDSTONE.

DISTRIBUTION.

The beds referable to the Dakota are exposed in an interrupted belt stretching from the middle of the southern border of the area to its northwest corner. South of the area mapped in this paper the Dakota outcrops continue past Boreas to Hamilton, and are shown by the Hayden map along the western edge of South Park. To the north the same map indicates

[1] Seventh Ann. Rept. Geol. and Geog. Survey Terr., for 1873, 1874, pp. 214, 216.

the general continuance of the Dakota belt along the Blue to its confluence with the Grand and far beyond the latter river into North Park. It also represents the formation as crossing the Park Range 30 miles northwest of Breckenridge and connecting directly with broad areas of the Dakota spread over hundreds of square miles of plateau country in western Colorado.[1] From the Dakota of the Great Plains the formation at Breckenridge is separated by the pre-Cambrian axial belt of the Front Range, the distance from Breckenridge eastward to Morrison being about 45 miles.

Within the narrow limits of the Breckenridge district the Dakota has been so broken by igneous intrusion and so dissected by erosion as to be little more than a chain of fragments. One very irregular area stretches from the south edge of the district across Illinois Gulch to Nigger Hill. It might be concluded from the relations shown by Plate I (in pocket) that the same formation extends continuously under the glacial and alluvial deposits past Breckenridge to Shock Hill. This, however, is not the case, for it is known that a large part of the older auriferous gravel between Breckenridge and French Creek rests on porphyry. On the other hand, dredging has shown that the quartzite of Nigger Hill is continuous with that exposed on the south slope of Prospect Hill. Another area extends over Gibson Hill and probably crosses under the gravels of the Blue to connect with the part of the formation that rests on the pre-Cambrian west of Braddocks. Other smaller fragments of the Dakota are exposed along the west side of the Blue from the Barton gulches to Shock Hill, along both sides of French Creek from its mouth to the vicinity of Lincoln, and at many places in contact with the great porphyry sheet of Bald Mountain.

THICKNESS.

The section of the Dakota exposed near Breckenridge Pass, just west of Boreas, affords a total thickness of about 200 feet. The only locality within the district mapped where a fairly full section of the formation can be measured is in the railway cut through Rocky Point. Here the total thickness of the beds supposed to belong to the Dakota is about 230 feet. They are conformably overlain by black Upper Cretaceous shale, the contact being well exposed. The base of the visible section is an intrusive sheet of porphyry underneath which are "Wyoming" beds.

It is possible that the Dakota sandstone as mapped in the Breckenridge district includes some beds belonging to the Morrison formation or to the Comanche series.

LITHOLOGY.

At Boreas the Dakota comprises the following units, numbered from the basal number up:

Section of the Dakota near Boreas.

	Feet.
3. Massive buff fine-grained sandstone	50
2. Thin-bedded reddish and gray sandy limestone with some pebbly grit and a little dark shale. Weather pink or light red as a whole	100
1. Light-gray or buff sandstone with pebbly streaks. Beds thinner than No. 3. Bottom bed, about 6 feet thick, contains abundant pebbles of white quartz mostly less than half an inch in diameter. This bed varies from coarse sandstone to fine conglomerate	50
	200

Farther north, within the boundaries of the mapped area, it has not proved possible to recognize the three divisions just given. This is perhaps due partly to the local dismemberment of the formation by igneous intrusions so that portions of it only are present in any one mass and partly to the fact that few of the natural exposures, owing to the prevalent low angles of dip, show sections of the beds, many of them exhibiting little more than the loose detritus derived from some particularly hard quartzitic stratum. The chief obstacle, however, in the way of any subdivision of the Dakota for the whole district is probably the muta-

[1] See Holmes, W. H., Ninth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., for 1875, 1877, p. 259; also Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and Utah: Jour. Geology, vol. 15, 1907, pp. 635–637.

bility of the formation. One variation noticeable in passing from Boreas into the mapped area is that the buff sandstone changes to hard white, gray, or buff quartzite. This quartzite is the distinctive feature of the Dakota throughout the district and, in consequence of its superior hardness, is as a rule much better exposed than the shaly and calcareous beds with which it is in most places closely associated.

At Rocky Point the railway cut affords the following section of beds striking northwest and dipping 65° NE.

Section of the Dakota at Rocky Point.

	Feet.
14. Thin-bedded gray quartzite; beds less than 1 foot thick; conformably overlain by Upper Cretaceous shale	18
13. Gray quartzite	3
12. Thin alternating beds of gray quartzite and shale; beds generally less than 6 inches thick	25
11. Quartzite	12
10. Dark shale	1
9. Quartzite	4
8. Thin shaly sandstone and gray shale	1.5
7. Massive quartzite	15
6. Alternating thin gray quartzite and gray to black shale	18
5. Massive gray quartzite, disturbed and broken near base	30
4. Disturbed red and green shale. Possibly some faulting here	25
3. Thin-bedded light-reddish sandstone and shale	40
2. Buff cross-bedded sandstone with a few small quartz pebbles	20
1. Brittle gray shaly limestone resting on porphyry sheet with igneous contact	20
	232.5

At several horizons, especially in the upper part of the section, the gray shales and thinner-bedded quartzite contain flakes of black carbonized vegetable material, but no identifiable plant remains were found.

It is clear that this section is distinctly different from that at Boreas, given on page 35. Above the thick buff sandstone at Boreas the beds are very poorly exposed, but are known to include some gray limestone and a little gray sandstone. Possibly some of these beds not included in the measured Boreas section are really equivalent to beds above No. 11 at Rocky Point. Even on that supposition there is no clear correspondence between the rest of the sections. The uncertainty regarding the base of the Rocky Point section adds to the difficulties of comparison. At first the base of the Dakota was supposed to be the bottom of bed 5, all below that being reddish and all above gray. It was found impracticable, however, to carry out this distinction along the ridge southeast of Rocky Point, and the lower beds of the section, notwithstanding their reddish tint, were found to be so different from the intensely red and micaceous sediments below the porphyry sill that they were finally mapped with the Dakota, although they may in part belong to the Morrison formation.

Overlying the "Wyoming" along the west slope of Bald Mountain, and separating that formation from the porphyry that forms most of the mountain, is a strip of the Dakota, shown in Plate I (in pocket). This strip is, as a rule, not well exposed, being covered in many places by porphyry detritus from the slopes above. The characteristic quartzite of the Dakota may be well seen, however, in the Gold Bell and Golden Edge workings east of the pre-Cambrian inlier of Illinois Gulch. In the Gold Bell the quartzite is interbedded with some gray shale and is overlain by limestone or calcareous shale, in places at least 30 feet thick, above which is the base of the Bald Mountain porphyry sheet. In the Golden Edge mine inclines and drifts have followed the bedding of the quartzite under the porphyry. South of this mine, where the slope is steeper, the first rock to outcrop above the red "Wyoming" beds is a hard buff quartzite, apparently about 150 feet thick. Probably considerable shale that does not outcrop is associated with this quartzite, which is overlain by nearly 100 feet of compact gray limestone interbedded with some calcareous gray shale and a little reddish shale.

The Dakota of the area southwest of the Mountain Pride mine consists mainly of nearly white quartzite interbedded with dark-gray shale containing coaly particles. A noteworthy characteristic of the quartzite of this area as well as of most others to the north is a deep, close pitting of the upper and lower surfaces of the beds along certain bedding planes, due to the corrosion of the quartz by atmospheric water. The kind of surface produced by this solution is illustrated in Plate XXXI, *A* (p. 160). The action is not noticeable on freely exposed surfaces of the quartzite, but apparently takes place wherever percolating water charged with organic acids from its passage through the soil penetrates the rock along bedding planes and remains in contact with the quartz long enough to effect its solution. The etching is similar to that described some years ago by C. W. Hayes.[1] The white quartzite and gray shale of the Mountain Pride mine pass downward into a massive light-buff to pinkish sandstone, below which are the red beds of the "Wyoming." All the beds are poorly exposed on this slope and the contact between the two formations is not visible.

The Dakota as represented in Illinois Gulch, on Little Mountain, and on Nigger Hill is chiefly white or light-yellowish quartzite. With this is associated a good deal of gray shale, in part calcareous, which is much more noticeable in underground workings than at the surface. The proportion of interbedded shale is rather high in the vicinity of the Puzzle and Ouray mines, as appears in the mines, although little of this rock is visible on the surface. Little Mountain and the west knob of Nigger Hill are composed of nearly horizontal beds of white quartzite up to 8 feet thick, interbedded with rather hard calcareous and siliceous gray shale. In the quartzite are a few thin conglomeratic bands with small quartz pebbles. These grade into the fine-grained quartzite. The lower slopes of both hills are cumbered with quartzite débris which conceals the rock in place. Material thrown out from some abandoned tunnels near the bottom of the slope consists in part of pink sandstone and shale resembling that near the base of the Rocky Point section. Similar material, largely shale, has been taken from a prospect shaft of unknown depth on Little Mountain. None of this material has the micaceous character of the typical "Wyoming" sediments.

The upper part of Gibson Hill is chiefly white or gray quartzite, much of which weathers rusty from the oxidation of disseminated pyrite. On the summit of the hill is a bed of dark grit in the quartzite, composed of angular bits of dark chert, up to a quarter of an inch in diameter, embedded in a matrix of smaller quartz grains. On the southwest slope of the hill this quartzite is associated in obscure stratigraphic relation with conglomeratic varieties containing scattered pebbles of white quartz and with shales that are in part micaceous. The dumps of the abandoned tunnels on the west slope of the hill show some reddish sandstone and shale, whose stratigraphic relations to the typical Dakota quartzite are unknown. Some shafts appear to have gone through this red material into quartzite below it. The crest of the broad spur extending from the north slope of Gibson Hill toward Braddocks is mostly hard white quartzite associated with some shale and containing at least one bed, fully 4 feet thick, of very hard conglomerate made up of quartz pebbles about the size of peas.

The quartzite areas west of the Blue are, as a rule, so poorly exposed that little can be learned of their lithology or stratigraphy. On the northeast side of Shock Hill, according to Mr. Bastin, there is a little purplish-red sandy shale interbedded with the quartzite. He notes also that at the base of the quartzite, resting on the pre-Cambrian, is a layer of gray grit or fine conglomerate associated with gray limestone and brick-red shale. The greatest thickness of conglomerate actually observed was 2 feet. The imperfectly rounded pebbles are chiefly quartz and pink feldspar, are generally less than an inch in diameter, and appear to have been derived from the pre-Cambrian rocks near at hand. There is perhaps some question whether these basal beds west of the Blue are part of the Dakota or represent the thin edge of the "Wyoming." It was not found practicable, however, to separate them from the Dakota quartzite in mapping.

In conclusion, the Dakota in the Breckenridge district is generally a hard, fine-grained, white or gray quartzite. At many places this is the only rock visible; in others it is interbedded with gray or more rarely red shale, and may contain calcareous or conglomeratic beds.

[1] Solution of silica under atmospheric conditions: Bull. Geol. Soc. America, vol. 8, 1897, pp. 213-220.

UPPER CRETACEOUS SHALE.

PRELIMINARY STATEMENT.

In the Breckenridge district the beds overlying the Dakota are dark shales with a few very subordinate thin layers of limestone and of gray quartzite. A few fossils known to be distinctly Benton, others fairly well determined as Niobrara, and some imperfect specimens that are possibly Montana species have been found in these beds in the course of the present investigation; but neither the available paleontologic evidence nor the lithologic character of the series justifies a local attempt at subdivision. The section is not only greatly affected by igneous intrusions, but it has no definite stratigraphic top, the beds, which dip generally to the east, being faulted down on that side against the pre-Cambrian. In view of these facts and of the great thickness of the series, which, as will presently be seen, much exceeds any that has been recognized for the Colorado Group alone in this latitude, the names given to the divisions of the Cretaceous above the Dakota in the central Great Plains region are not here applicable. The development of the shale strongly suggests the Mancos of western Colorado, but, for reasons given in the section on correlation, the use of the name Mancos shale for the formation near Breckenridge is scarcely warranted by present knowledge of the stratigraphy of central Colorado. Accordingly, it has seemed best to refer to the shale in this report as Upper Cretaceous shale, or occasionally more briefly in the body of the text as black shale. If subdivision into smaller units is ever effected this will probably be by approach from the north, where along the lower course of the Blue, as the work of Marvine indicates, there are sections more suitable than those near Breckenridge for stratigraphic study.

DISTRIBUTION.

The Upper Cretaceous shale, very intricately intruded by porphyry, occupies the northeast half of the district with the exception of a small area of pre-Cambrian, against which the shale is faulted, in the extreme northeast corner. (See Pl. I, in pocket.)

Not only has the porphyry invaded the shale in an exceedingly irregular manner, but the igneous rock has inclosed innumerable small masses of the sedimentary rock, of which a few only of the larger and better exposed ones can be shown on the geologic map. Along the eastern border of the district the shale extends continuously from the head of French Gulch over Farncomb Hill and across the Swan to Muggins Gulch.

Some Upper Cretaceous shale occurs also in the southwest half of the district on Shock Hill, between Prospect and Gibson hills, in Illinois Gulch, and in a belt extending from Little Mountain past Rocky Point to Bacon. It is probably the principal bedrock of French Gulch between the Wellington or Country Boy mine and Lincoln, but here, as in many other places, its exposures are very inconspicuous and the shale is more subject than other rocks in the district to concealment by soil and forest.

LITHOLOGY.

The Upper Cretaceous shale is generally dark gray to black, carbonaceous, calcareous, highly fissile, and rather soft, breaking into small flakes when exposed for a few years to the weather. Much of it as seen in fresh underground exposures is coal-black. It exhibits, however, considerable variation. This is due in part to metamorphism by the intruded porphyry masses, but in part also to original differences in composition. Some is hard, light gray, and siliceous, grading into fine-grained gray quartzite or into compact cherty and calcareous beds. Such varieties lack the fissility of the softer shale and, as they resist erosion better, they may form steep slopes and outcrop on peaks and along ridges, as on Brewery Hill or on the spur of Mount Guyot between French and Little French gulches. Thin lenses of fetid fossiliferous limestone occur at many localities and do not appear to be specially characteristic of any particular horizon in the formation. The color of the weathered shale is far from uniform. Although generally black or somber gray, the formation in some places weathers red-brown, buff, or light gray. With this preliminary general characterization of the shale attention may now be given to a few of its local variations.

The shale of the Rocky Point, Gibson Gulch, Gold Run, and Delaware Flats areas is nearly all of the soft, black fissile variety that in the development of the topography tends to the formation of ravines and swales with no projecting outcrops. An exception to this is found on the hill east of Gibson Gulch, where the shale, apparently metamorphosed by intrusions of diorite porphyry, is hard, cherty, and of light greenish gray color. Similar soft black shale occurs along French Gulch and in the vicinity of Lincoln Park. Much of the shale of Farncomb Hill also is of similar kind but on the whole is a slightly harder rock that grades to the north, east, and south into some of the most resistant facies of the formation. The lower west slope of Mount Guyot, Little French Gulch, and the steep spur east of Monitor Gulch are all carved from hard, ringing dark shales very different in appearance from those exposed along the bottoms of American and Georgia gulches. Yet the one set of beds strikes directly into the other and the clinking shales of Mount Guyot, which weather in warm red-brown tints, are stratigraphically continuous with the gray banded cherty shales east of Monitor Gulch and with the black shales of American and Georgia gulches, which split into fragile flakes where laid bare by placer mining. These in turn strike into the generally hard and rather flinty shales of Brewery Hill.

On the south side of the Swan, just east of Rock Island Gulch, the shales are well exposed in the sides and bottom of a large ditch or small canal. Here they are rather sandy, yellowish brown in color, and flecked with shadowy dark spots that possibly are fragmentary plant remains. This same band of brown sandy shale can be traced southward past Snyder's placer camp, near bench mark 9823.

North of the Swan, in the vicinity of Muggins Gulch, the shales are rather variable. They contain, together with a good deal of fissile black shale, some bands of fine-grained dark-gray quartzite, apparently not of great persistency, some hard dark shale identical with that on the west slope of Mount Guyot, some very compact gray bands suggestive of silicified calcareous shale, and a little gray limestone. The assemblage on the ridge east of Muggins Gulch suggests on the whole the hard beds of upper French Gulch or of the northeast slope of Brewery Hill rather than the fissile shales of Farncomb Hill; but, as is commonly the case in the shale areas, soil and vegetation greatly obscure the details in the relations of the various beds.

THICKNESS.

It is not possible to make an accurate estimate of the thickness of the Upper Cretaceous shale in the Breckenridge district. Even were the total thickness measurable the figure obtained would represent only a part of the whole, as some of the upper beds of the formation are known to have been removed by erosion. The distance across the strike of the shale from the diorite porphyry south of Farncomb Hill to the end of the spur east of Monitor Gulch is about 8,000 feet. The observed dips along this section range from 35° to 60° and the average may be taken as 45°. The dip is uniformly northeast and as there are no large intrusions of porphyry crossed by the section the horizontal distance of 8,000 feet corresponds to a thickness of about 5,500 feet, provided that there is no important duplication of beds by faulting. Similar measurements at the head of French Gulch and over Brewery Hill give results of the same order of magnitude. In the steep slope east of French Gulch and south of Little French Gulch the beds are well exposed, dip uniformly to the east, and present no evidence of important faulting; yet this section alone indicates a thickness of 3,500 feet. If measurement is confined merely to the spur east of Monitor Gulch, where it appears impossible that any duplication by faulting could escape notice and where the dip is very regular, a thickness of 3,000 feet is obtained. In comparison with these figures, the maximum thickness of the Colorado group in eastern Colorado as given by Darton [1] is 1,430 feet, or less than half the thickness calculated for the Breckenridge district. This discrepancy is so great as to render it necessary to suppose either that faulting, resulting in repetition of the beds, has been much more important than study of the surface relations of the rocks indicates, or that the dark shales of the district include beds corresponding to part of the Montana group, and thus represent a development

[1] Darton, N. H., Geology and underground waters of the central Great Plains: Prof. Paper U. S. Geol. Survey No. 32, 1905, p. 76.

similar to that of the Mancos shale in western Colorado. The latter is regarded as the more likely supposition of the two. Probably when detailed geologic work is taken up 8 or 10 miles north of Breckenridge, where the shale is extensively exposed and apparently is less disturbed and indurated by porphyry intrusions than in the area now under investigation, a much more satisfactory estimate of the thickness and constitution of the formation can be made.

CORRELATION.

Along the eastern front of the Rocky Mountains, in the central Great Plains region, that part of the Upper Cretaceous lying above the Dakota and below the "Laramie" is generally divisible into two groups—the Colorado group, in part subdivisible into the Benton and Niobrara formations, and the Montana group, subdivisible into the Pierre and Fox Hills formations, or, in some parts of the field, into more numerous units. At Morrison, 45 to 50 miles east of Breckenridge and on the opposite side of the Front Range, Eldridge[1] found above the Dakota (*a*) 500 feet of dark Benton shale, (*b*) 400 feet of Niobrara, consisting of limestone, gray marly clays, and yellow or buff shales, (*c*) 7,700 to 7,900 feet of Pierre, consisting of plastic lead-gray, bluish and yellowish clays with a zone of sandstone from 100 to 350 feet thick about one-third of the way from the base to the top of the formation, and (*d*) 800 to 1,000 feet of the Fox Hills formation, chiefly arenaceous shale.

In the vicinity of Breckenridge the geologists of the Hayden Survey evidently saw no sedimentary rocks above the Dakota and mapped the shale and intruded porphyry of the northeastern part of the district as Archean. South and north of the Breckenridge area, however, the Hayden atlas shows the Dakota as overlain by the Colorado group and this by the Laramie, no Montana (Fox Hills or Pierre) being indicated.

Eldridge[2] in 1894, as a result of his study of the Anthracite-Crested Butte area, 50 miles southwest of Breckenridge, on the other side of the Sawatch uplift, described the Dakota as overlain by 150 to 300 feet of dark Benton shale. This is succeeded, according to Eldridge, by the Niobrara formation, consisting of 20 to 40 feet of limestone overlain by 80 to 160 feet of gray calcareous shale. Above these is the Montana group, embracing about 2,500 feet of leaden-gray clays with numerous lenses of limestone assigned to the Pierre and about 300 feet of alternating clays and sandstones assigned to the Fox Hills.

In the Aspen district, just north of the Anthracite-Crested Butte area, Spurr[3] made a similar division of the Cretaceous rocks above the Dakota. Here he found black calcareous Benton shale 350 feet thick, succeeded by dense limestone 50 to 75 feet thick, overlain by shaly limestone. This limestone, with a total thickness of about 100 feet, Spurr assigned to the Niobrara. Above the Niobrara is a great thickness, probably near 4,000 feet, of gray or black shale with thin lenticular beds of limestone. This is referred to the Montana group, the Pierre and Fox Hills formations not being distinguished.

It thus appears that the Breckenridge district lies between the Great Plains region on the east and the Crested Butte and Aspen region on the southwest, in both of which the Upper Cretaceous beds are susceptible of the same general division into the Dakota, the Colorado group, containing the Benton and Niobrara, and the Montana group. It would naturally be expected that the beds at Breckenridge would be separable into the same units. This is not the case; but before the divergency is discussed attention may be turned for a moment to western Colorado.

When Cross[4] in 1899 published the first of his series of folios on the San Juan region, in southwestern Colorado, he described nearly 2,000 feet of dark shale above the Dakota, to which he gave the name Mancos shale. This was shown to carry fossils elsewhere characteristic of the Benton, Niobrara, and Pierre formations but to be not divisible into equivalent litho-

[1] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 51–72.

[2] Anthracite-Crested Butte folio (No. 9), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

[3] Spurr, J. E., Geology of the Aspen mining district, Colorado: Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 41–43.

[4] Cross, Whitman, Telluride folio (No. 57), Geol. Atlas U. S., U. S. Geol. Survey, 1899. See also folios 60, 130, and 153.

logic units. When Fenneman and Gale[1] took up the study of the Yampa coal field in northwestern Colorado they were confronted with stratigraphic conditions similar to those in southwestern Colorado. In other words, they found overlying the Dakota approximately 2,500 feet of shale, with very subordinate limestone and sandstone members, which they correlated with the Mancos shale. Taff[2] has described similar relations in central Utah, the coal-bearing Mesaverde formation being underlain by fully 1,500 feet of Mancos shale, and Gale[3] has since extended his earlier observations on the Mancos in the extreme western part of Colorado, where he finds the shale to attain a thickness of about 5,000 feet. The general result of all these studies has been to show a decided difference in the lithology of the Colorado and Montana groups of the Cretaceous in eastern and western Colorado. One of the first stratigraphic questions that arose when field work at Breckenridge was begun was whether the post-Dakota Cretaceous would be found to correspond to the Great Plains section, such as is exposed only 45 miles away on the other side of the Front Range, or whether it would correspond to the sections of western Colorado, with the Mancos shale, representing all of the Colorado and part of the Montana group. The latter appears to be the case, there being no distinct and persistent calcareous formation recognizable as the Niobrara, and were it not for the work of Eldridge at Crested Butte and of Spurr at Aspen the shale at Breckenridge would be referred to the Mancos. Under the circumstances outlined, however, it is deemed best to defer actual correlation until more is known of the Cretaceous section north and south of Breckenridge, particularly as in that district the conditions for stratigraphic study are far from favorable and the original lithologic character of the shale may have been considerably modified by the porphyry intrusions.

Fossils are not abundant in the black shale as developed near Breckenridge, but have been found at a few places in different parts of the district. The small collections made were submitted to Dr. T. W. Stanton, who kindly identified the species represented.

In a small cut close to the railway and 1,500 feet southeast of the summit of Little Mountain, thin-bedded limestone and calcareous shale, interbedded with softer black shale, carry imperfectly preserved shells of *Inoceramus deformis* Meek (?). If correctly identified, this fossil is indicative of the lower part of the Niobrara, according to Mr. Stanton. The beds strike N. 55° W. and dip 60° SW. They are intruded by porphyry and their stratigraphic height above the Dakota is not determinable from their field relations, although these are more suggestive of the lower than of the upper part of the formation.

In thin dark fetid limestone 500 feet north of the Rocky Point cut and below the railway were collected *Ostrea lugubris* Conrad, *Inoceramus fragilis* H. and M., and *Scaphites warreni* M. and H. These, according to Mr. Stanton, are upper Benton species. Here again proximity to intrusive porphyry renders useless an attempt to fix by ordinary stratigraphic observations the exact place of the fossils in the geologic column, but there is nothing in the visible structure to suggest that they occur at a horizon any lower than that of the *Inoceramus deformis* near Little Mountain. A bed of fetid limestone identical in appearance with that near Rocky Point occurs with dark shale in the railway cut 500 feet south of Bacon. Although it contains abundant remains of shell fragments no identifiable fossils could be found.

In the dark shale on the south edge of Delaware Flats Mr. Bastin collected specimens of *Inoceramus labiatus* Schlotheim (?), and the same fossil was found in harder shale 1,000 feet east of the head of Monitor Gulch, east of Farncomb Hill. This species, if correctly identified, indicates beds lower in the Benton than those carrying *Ostrea lugubris*, according to Mr. Stanton, whereas stratigraphically it appears in this district to be higher and occurs about 4,000 feet above the Dakota, provided no faulting has essentially modified the structure. Mr. Stanton states, however, that the determination is uncertain and that the specimens doubtfully referred to *Inoceramus labiatus* may really be a Montana form.

[1] Fenneman, N. M., and Gale, H. S., The Yampa coal field, Routt County, Colorado: Bull. U. S. Geol. Survey No. 297, 1906.

[2] Taff, J. A., The Pleasant Valley coal district, Carbon and Emery counties, Utah: Bull. U. S. Geol. Survey No. 316, 1907, p. 341.

[3] Gale, H. S., Geology of the Rangely oil district, Rio Blanco County, Colorado, with a section on the water supply: Bull. U. S. Geol. Survey No. 350, 1908, pp. 26–32.

Inoceramus deformis Meek has also been found poorly preserved in shale 200 feet north of Lincoln, and in better, though distorted, specimens, definitely identified by Mr. Stanton, in Summit Gulch near its mouth.

A single specimen of *Inoceramus* collected by Mr. D. Foster Hewett near the summit of Farncomb Hill, just west of the head of Monitor Gulch, is not well enough preserved for identification, but according to Mr. Stanton suggests the Montana group species, such as *Inoceramus cripsii*, rather than any common species of the Colorado group. Fragments, apparently of the same fossil species, were noted at one or two places in the loose shale on the south slope of Farncomb Hill, east of the Wire Patch mine.

The fossils found near Breckenridge thus indicate that the shale represents both Benton and Niobrara time and possibly also part of Montana time, although neither the paleontologic nor the stratigraphic data suffice for local subdivision into the corresponding formations. Paleontology and lithology both suggest the same conclusion—that in the region drained by the Blue the Cretaceous beds above the Dakota show the development characteristic of western and not of eastern Colorado. If true, this extends the known range of the Mancos phase of sedimentation to the east and brings it within 45 miles of the eastern phase as exemplified by the Morrison section. The relation of the Breckenridge section to that at Crested Butte is a problem awaiting investigation.

CHAPTER III.

PETROGRAPHY OF THE IGNEOUS ROCKS.

GENERAL FEATURES.

EARLIER STUDIES.

The porphyritic intrusive rocks of the Breckenridge district have certain characteristics of composition and texture that, as Cross [1] has shown, are common to the late Cretaceous or Tertiary intrusives of a region stretching from Boulder County southwestward across the State of Colorado into Utah and Arizona. Recently S. H. Ball [2] has reviewed the literature of these porphyries and has approximately outlined the belt of their occurrence in central Colorado. In the same report J. E. Spurr and G. H. Garrey emphasize the geographic coincidence of this belt of generally monzonitic porphyries with the principal metalliferous deposits of the State and show that there is probably a genetic relation between the two.

In the Tenmile district the porphyries, according to Cross,[3] grade from the more salic to the more femic varieties. Three types, the Lincoln, Elk Mountain, and Quail porphyries, are in that area distinguished and mapped by Emmons,[4] but it is clear from his descriptions that these are variants from one general monzonitic magma and are connected by intermediate facies. In the Leadville district Cross [5] distinguished (1) quartz porphyry or Mount Zion porpyhry, (2) white or Leadville porphyry, (3) pyritiferous porphyry, (4) Mosquito porphyry, (5) Lincoln porphyry, and (6) gray porphyry. This classification depends in part on local alteration of the porphyries in the vicinity of the Leadville ore bodies and is of little use outside of that district; the only one of the six types that appears to be generally recognizable north of the Leadville area is the Lincoln porphyry, with its characteristic large phenocrysts of orthoclase and smaller though conspicuous grains or crystals of quartz. Neither at Leadville nor in the Tenmile district do the geologists appear to have discovered evidence that any of the types of porphyry are distinctly older or younger than others.

RELATION TO PORPHYRIES OF NEAR-BY DISTRICTS.

The intrusive rocks of Breckenridge are not only in the same general belt or province as those of Leadville and the Tenmile district, but they belong with them to one local petrographic field, and the geologist passing southward from Breckenridge to Leadville by way of Mounts Silverheels and Lincoln finds the same familiar kinds of porphyry recurrent along his route. This holds true also between Leadville and the Tenmile district. Between the Tenmile Valley and that of the Blue at Breckenridge intervenes the pre-Cambrian ridge of the Tenmile Range, which constitutes a local barrier between the intrusives in the sediments of the two districts. Probably, however, a close examination of this range would show some direct connection between the porphyries of the Tenmile and Breckenridge districts through intrusions in the pre-Cambrian rocks.

[1] Cross, Whitman, The laccolitic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 165-241.

[2] Prof. Paper U. S. Geol. Survey No. 63, 1908, pp. 67-70, Pl. XI.

[3] Op. cit., pp. 222-224.

[4] Tenmile special district folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[5] Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 323-333.

TYPES OR VARIETIES.

Within the Breckenridge district the intrusive porphyries may conveniently be considered as belonging to three types. These are (1) the silicic type, exemplified by quartz monzonite porphyry with phenocrystic quartz; (2) the calcic type, exemplified by monzonite porphyry, locally grading into diorite porphyry, with only incidental quartz in the groundmass; and (3) the intermediate type in which quartz forms very inconspicuous phenocrysts or belongs solely to the groundmass. Although, as will be seen, these varieties are not all of precisely the same age they are connected by many intermediate facies and are believed to be closely related as slightly differentiated products of one magma.

QUARTZ MONZONITE PORPHYRY.

MEGASCOPIC CHARACTER.

The silicic type of porphyry (Lincoln porphyry of the Tenmile folio) is generally a light-colored rock, being as a rule pale gray and weathering to buff or brown tints or to a fainter shade of green than the other porphyries. (See Pl. VI.) It is as a rule conspicuously porphyritic. Rounded or bipyramidal phenocrysts of quartz up to a centimeter in diameter, large well-formed crystals of orthoclase up to 8 centimeters in length, and smaller phenocrysts of plagioclase contrast conspicuously with the generally rather dense fine-grained groundmass. In some varieties small phenocrysts of biotite, the scales being rarely over 3 millimeters across, are abundant; in others dark phenocrysts are nearly absent. Hornblende is visible in some facies but is not characteristic of the silicic type and where present appears to indicate a transition toward the calcic type. The principal field criterion for the distinction of the quartz monzonite porphyry from the monzonite porphyry is the presence of phenocrysts of quartz and orthoclase, this feature commonly being associated with characteristic differences in color and texture. As a rule there is no difficulty in distinguishing these two kinds of porphyry, the rock of the large irregular intrusive mass exposed along both sides of the Swan, for example, being decidedly different in color, texture, and mode of weathering from that forming the upper part of Bald Mountain and the slopes of French Gulch west of Lincoln. Other masses, however, as will be shown later, are intermediate in character between the two types.

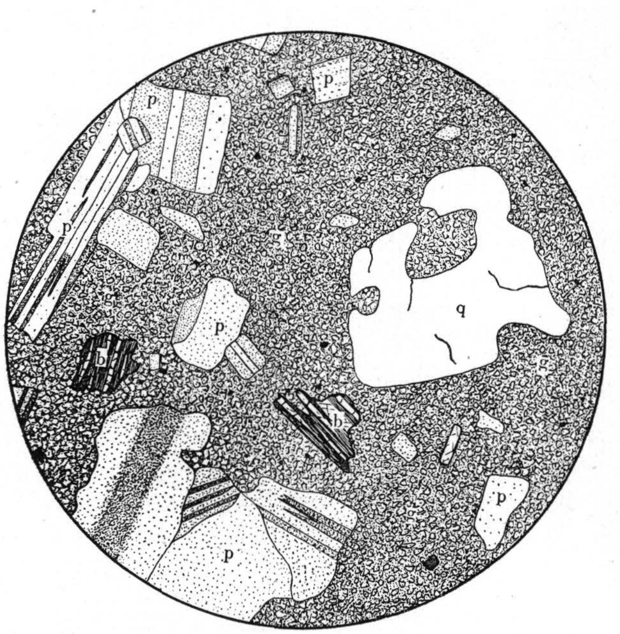


FIGURE 2.—Characteristic texture of quartz monzonite porphyry (silicic type) as seen in thin section, with nicols crossed. ×30. Drawn by aid of the camera lucida. q, Quartz; p, plagioclase; b, biotite; g, groundmass, chiefly of orthoclase and quartz.

MICROSCOPICAL CHARACTER.

Under the microscope the silicic type of porphyry generally shows a sharper distinction between phenocrysts and groundmass than does the calcic type. The phenocrysts are comparatively large and well formed, and the groundmass is fine grained and equally granular. Consisting almost wholly of quartz and orthoclase, the groundmass presents the appearance (see fig. 2) of a fine mosaic of closely fitting irregular grains, of which the average diameter ranges in various specimens from 0.02 to 0.08 millimeter. The absence of the more or less euhedral lath-shaped sections of plagioclase found in the calcic type results in a noticeably different texture of the groundmass, as may be seen by comparing figures 2 and 3 (pp. 44, 51). Neither poikilitic nor micropegmatitic textures are characteristic of the groundmass in the silicic type.

The very conspicuous phenocrysts of orthoclase in this rock, owing to their size, do not as a rule appear in thin sections, where phenocrysts are almost exclusively plagioclase, generally andesine, corresponding to the formula Ab_1An_1. In other words, orthoclase occurs as large megascopic phenocrysts and in the groundmass, but not as a rule in phenocrysts such as are ordinarily included in microscopical sections. Phenocrysts of quartz, generally showing more or less magmatic corrosion, are abundant. Nearly all thin sections show some biotite phenocrysts, but hornblende is exceptional. In the silicic type allanite is more common and occurs in larger crystals than in the calcic type.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of the silicic type is represented by the following two analyses:

Chemical analyses of quartz monzonite porphyry.

[R. C. Wells, analyst.]

	1	2		1	2
SiO_2	67.53	68.14	CO_2	0.03	0.22
Al_2O_3	15.46	15.29	P_2O_5	.01	.17
Fe_2O_3	2.18	.35	FeS_2	.09	1.52
FeO	2.42	1.66	F	.03	None.
MgO	[a] .16	.26	Cr_2O_3	None.	
CaO	3.24	3.03	NiO_2	None.	.01
Na_2O	3.24	3.59	MnO	.10	.12
K_2O	3.86	4.07	BaO	.07	.03
H_2O-	.23	.40	SrO	None.	.03
H_2O+	.55	.39		99.63	99.65
TiO_2	.41	.36			
ZrO_2	.02	.01			

[a] Probably a little low.—F. L. R.

1. Quartz monzonite porphyry. Amiatose (Br. 104). Brewery Hill, 1,000 feet northeast of summit.
2. Quartz monzonite porphyry. Toscanose (Br. 110). Browns Gulch, 900 feet south of Swan City.

Sample 1 was taken from some large fresh masses blasted from the roadway. This rock, shown in Plate VI, *B* (p. 44), is bright gray, speckled with small crystals of biotite, and has almost a granitic texture and appearance. Rather unevenly distributed through it are large crystals of orthoclase up to several inches in length and generally twinned in accordance with the Carlsbad law. These are more abundant on the summit of the knob northeast of Brewery Hill than at the exact spot where the sample was taken. In addition to the large crystals are abundant phenocrysts of quartz and plagioclase up to a centimeter across, many smaller ones of biotite, and rarely a small prism of hornblende. The rock is much nearer monzonite or granite in texture than most of the quartz monzonite porphyry of the district.

Under the microscope in thin section (see Pl. VII, *B*) the most abundant large phenocrysts are plagioclase, the orthoclase phenocrysts, owing to their size, being not as a rule included in the chips used for microscopic sections. The plagioclase in the specimen analyzed shows some zonal structure and has not been sharply determined. Its refractive index and extinction angles, however, indicate an andesine or sodic labradorite. The crystals are subhedral to anhedral, and are twinned in accordance with the albite, Carlsbad, and pericline laws. Some of the plagioclase phenocrysts are really aggregates of anhedral crystals, which as a rule poikilitically inclose grains of quartz and crystals of biotite. The quartz is wholly anhedral and is confined to the groundmass, in which the average diameter of grain is about 0.3 millimeter. The orthoclase, exclusive of the large phenocrysts, is also anhedral, with a tendency to form poikilitic aggregates with the other minerals. In contrast with the clear plagioclase it has generally a gray turbid appearance. It is not noticeably perthitic. The hornblende and biotite, which are in part intergrown, present no features of special note. Other minerals microscopically visible are magnetite, pyrite, apatite, titanite, zircon, allanite, and a very small quantity of calcite and chlorite.

PLATE VII.

PHOTOMICROGRAPHS OF PORPHYRIES.

A. Monzonite porphyry, near diorite porphyry. Wellington mine. ×40. Nicols crossed.

Illustration shows little more than the general texture of the rock, which contains hypersthene. For description see page 55.

B. Quartz monzonite porphyry. East slope of Brewery Hill. ×40. Nicols crossed.

Described with chemical analysis on page 45. o, Orthoclase; p, plagioclase; q, quartz; bi, biotite. Illustrates coarsely crystalline siliceous variety.

C. Quartz monzonite porphyry. Slope east of Hoosier Pass. ×40. Nicols crossed.

Illustrates well the usual texture of the siliceous variety. p, Plagioclase; bi, biotite; q, quartz; py, pyrite; ap, apatite. The biotite is partly chloritized.

A. BROWNS GULCH NEAR CASHIER MINE.

Shows conspicuous phenocrysts of orthoclase. Natural size. See page 49.

B. EAST SLOPE OF BREWERY HILL.

More granular texture than specimen shown above. Natural size. Described with chemical analyses on pages 45–49.

QUARTZ MONZONITE PORPHYRY, SILICIC VARIETIES.

The ideal norm of the quartz monzonite porphyry of Brewery Hill, calculated from analysis No. 1 for the purpose of ascertaining the place of the rock in the American system[1] of classification, is as follows:

Norm of quartz monzonite porphyry of Brewery Hill.

Quartz	25.56
Orthoclase	22.80
Albite	27.25
Anorthite	16.12
Hypersthene	2.51
Magnetite	3.25
Ilmenite	.76
	98.25
Pyrite	.09
Water	.78
	99.12

In the terminology of that system the rock is persalic, quardofelic, alkalicalcic (but near domalkalic), and sodipotassic. It is thus amiatose but is near toscanose.

The rock is wholly crystalline, and it is possible, with the aid of the microscopical study, to calculate approximately from the chemical analysis the actual mineralogical composition. For this purpose it is assumed that the hornblende in the rock is of the same composition as the hornblende in the quartz monzonite near Mount Hoffmann, Cal., and that the biotite is identical with the biotite in the quartz monzonite of the Nevada Falls trail, Yosemite Valley. These are as follows:

Analyses of hornblende and biotite.

	1	2		1	2
SiO_2	47.49	35.75	Cr_2O_3	....	Trace.
Al_2O_3	7.07	14.70	NiO	0.02	0.02
Fe_2O_3	4.88	4.65	MnO	.51	.45
FeO	10.69	14.08	BaO	....	.12
MgO	13.06	12.37	F	.06	.17
CaO	11.92	.17	V_2O_3	.04	.05
Na_2O	.75	.32			
K_2O	.49	9.19		100.05	99.90
H_2O+	1.86	3.64	O=F	.02	.07
H_2O-	....	1.03			
TiO_2	1.21	3.16		100.03	99.83
P_2O_5	....	.03			

1. Hornblende. From quartz monzonite (toscanose), Tioga Road, southeast of Mount Hoffmann, Cal. W. F. Hillebrand, analyst. Turner, H. W., Am. Jour. Sci., 4th ser., vol. 7, 1899, p. 297; Cross, Iddings, Pirsson, and Washington, op. cit., Table XIII, *a;* Bull. U. S. Geol. Survey No. 168, 1900, p. 208; Bull. U. S. Geol. Survey No. 419, 1910, p. 267.
2. Biotite. From quartz monzonite (toscanose), Nevada Falls trail, Yosemite Valley. W. F. Hillebrand, analyst. Turner, H. W., Am. Jour. Sci., 4th ser., vol. 7, 1899, p. 294; Cross, Iddings, Pirsson, and Washington, op. cit., Table XIV, *b;* Bull. U. S. Geol. Survey No. 419, 1910, p. 289.

The preliminary calculation gives the following:

Tentative mineralogical composition of quartz monzonite porphyry from Brewery Hill.

	Per cent by weight.
Quartz	27.14
Orthoclase	20.57
Albite	27.25
Anorthite	14.46
Biotite	3.46
Hornblende	1.11
Magnetite	3.02
Titanite	.98
Pyrite	.09
H_2O, not used in calculating minerals	.74
	98.82
Apatite, zircon, allanite, etc	.81
	99.63

[1] Cross, Whitman, Iddings, J. P., Pirsson, L. V., and Washington, H. S., The quantitative classification of igneous rocks, Chicago, 1903.

The calculation requires 0.48 per cent more magnesia and 0.79 per cent less ferrous oxide than are reported in the chemical analyses, so that the mica actually present is perhaps more ferruginous and less magnesic than the biotite from the California rock.

In this statement of composition the feldspars are given as if they were chemically pure. In reality most of the albite is combined with the anorthite as andesine or labradorite, and there is the possibility of a small remainder being combined with the potassium-aluminum silicate as orthoclase. Hillebrand[1] has analyzed the orthoclase phenocrysts from the "gray porphyry" of Johnsons Gulch, near Leadville, as follows:

Chemical analysis of orthoclase.

SiO_2	66. 22
Al_2O_3	20. 33
CaO	2 95
Na_2O	3. 45
K_2O	8. 31
H_2O	1. 90
	99. 16

The lime in this analysis shows that some plagioclase was present in the material used. The molecular ratio of CaO to Na_2O is 52 to 55, corresponding nearly to the plagioclase formula Ab_2An_1, or andesine. In other words, the soda present is not in excess of what might reasonably be supposed to be combined with lime in the plagioclase molecule, and the orthoclase itself presumably contains little soda. This agrees with the general absence of perthitic intergrowths shown by microscopical studies of these porphyries and with the observed inclusion of plagioclase in some of the large orthoclases. Inasmuch, however, as chemical analyses of rock-making orthoclase very rarely show less than 1 per cent of Na_2O, it is safe to include at least this quantity in the Breckenridge mineral and consequently to assume that for every 10 molecules of potash in the orthoclase there is present one molecule of soda.[2] On this supposition the mineralogical composition of the porphyry becomes as follows:

Mineralogical composition of quartz monzonite porphyry from Brewery Hill.

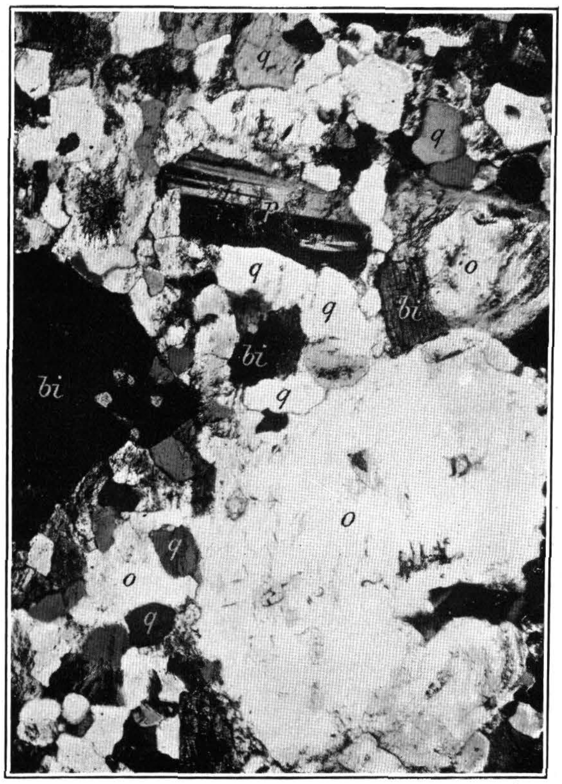
Quartz	27. 14
Orthoclase	22. 67
Andesine ($Ab_{66}An_{34}$, or nearly Ab_2An_1)	39. 61
Biotite	3. 46
Hornblende	1. 11
Magnetite	3. 02
Titanite	. 98
Pyrite	. 09
H_2O, not used in calculation	. 74
	98. 82
Apatite, zircon, allanite, etc	. 81
	99. 63

[1] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 333; Bull. U. S. Geol. Survey No. 419, 1910, p. 257.

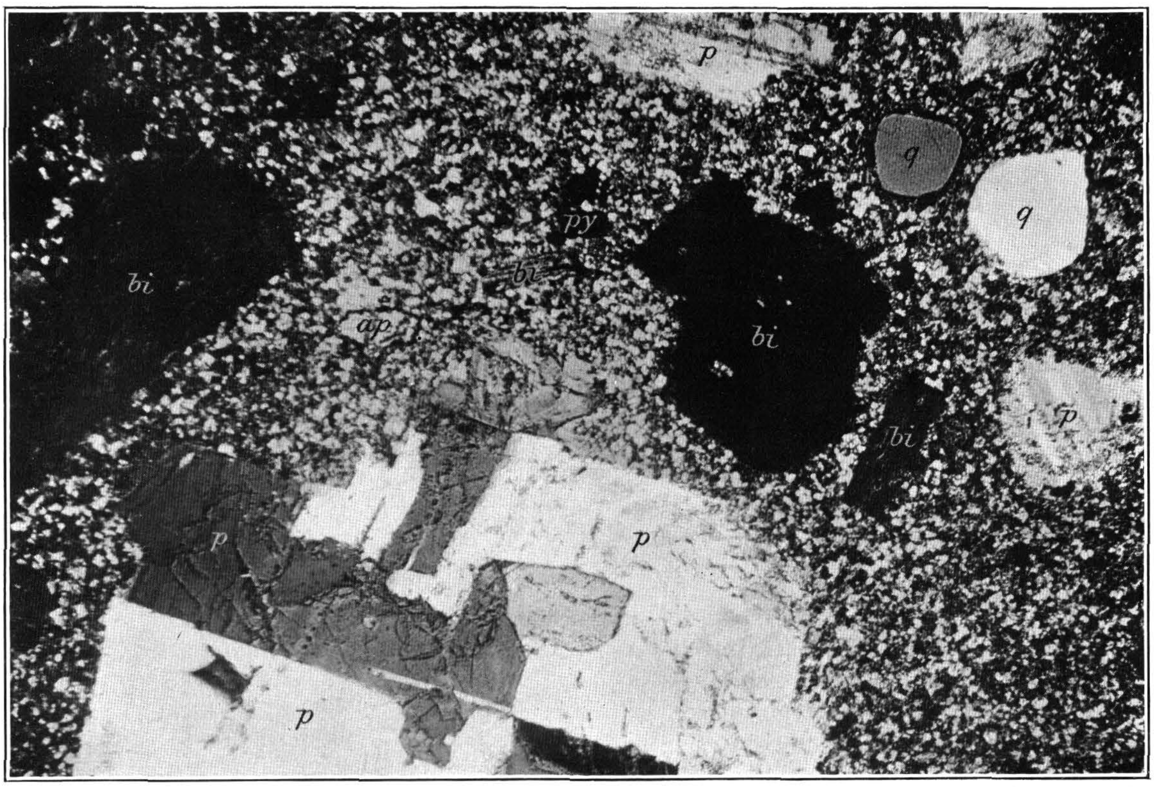
[2] That is, the composition of the orthoclase is supposed to be—

	Per cent.	Molecular ratios.
SiO_2	64. 40	1. 068
Al_2O_3	18. 87	. 185
K_2O	15. 73	. 067
Na_2O	1. 00	. 006
	100. 00	

A.



B.



C.

PHOTOMICROGRAPHS OF PORPHYRIES.

According to Lindgren,[1] the plagioclase in granodiorites is at least double the alkali feldspar and the latter ranges from 8 to 20 per cent. The porphyry of Brewery Hill is clearly monzonitic and not granodioritic. It is a little nearer to the intermediate type than much of the quartz monzonite porphyry mapped as the silicic type on Plate I (in pocket).

The quartz monzonite porphyry from the mouth of Browns Gulch is representative of the porphyry exposed along this gulch to its head and of much of that along both sides of the Swan. The rock is light gray and consists of conspicuous well-formed phenocrysts of orthoclase up to 2 inches or so in length, and smaller ones of quartz in a fine-grained groundmass that is speckled with biotite and sparkles with minute disseminated crystals of pyrite. The orthoclase phenocrysts are fairly clear and vitreous. The specimen illustrated in Plate VI, *A* (p. 44), while not from the same place in Browns Gulch, is representative of the rock here described.

Under the microscope the rock, notwithstanding the development of pyrite, is seen to be not much altered. In addition to the large orthoclases, phenocrysts of plagioclase, quartz, biotite, apatite, and, rarely, allanite lie in a fine-grained, evenly granular groundmass of quartz and orthoclase. The plagioclase is subhedral to anhedral and is andesine or oligoclase. Some of the crystals are partly altered to calcite, with probably some kaolin. The quartz phenocrysts are rounded and embayed, lacking the fairly sharp bipyramidal form characteristic of them in much of the silicic type of porphyry. Although many of the biotite crystals are quite fresh, others are partly changed to chlorite. Apatite occurs in crystals large enough to be conspicuous among the microphenocrysts and attains lengths up to a millimeter. Allanite, the characteristic occurrence of which in these Colorado porphyries was first recognized by Iddings and Cross,[2] forms small stout prisms of the usual epidote habit, elongated parallel with the *b* axis and twinned on the orthopinacoid (100). The crystals of allanite in the rocks of the Breckenridge district are generally less than half a millimeter in length and many of them are minute anhedral grains recognizable as allanite only by their color, pleochroism, and index of refraction. It is rare that one thin section shows more than two or three crystals of allanite and some sections contain none of the mineral.

The secondary minerals present are epidote, calcite, chlorite, and pyrite. The last has formed chiefly along cracks and on contact surfaces between other minerals.

The norm of this rock, the basic constituents of pyrite and other secondary minerals being calculated as if in their original combinations, is as follows:

Norm of quartz monzonite porphyry from Browns Gulch.

Quartz	24.42
Orthoclase	23.91
Albite	30.39
Anorthite	13.62
Diopside	.46
Hypersthene	1.82
Magnetite	2.09
Ilmenite	.61
Apatite	.34
	97.66
Water	.79
	98.45

This norm corresponds to toscanose.

[1] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, 1900, p. 277.

[2] Iddings, J. P., and Cross, Whitman, On the widespread occurrence of allanite as an accessory constituent of many rocks: Am. Jour. Sci., 3d ser., vol. 30, 1885, pp. 108-111. Also Cross, Whitman, The laccolitic mountain groups of Colorado, Utah, and Arizona: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 165-241, especially p. 223.

A preliminary calculation of the mode or actual mineralogical composition of the rock, the biotite being assumed to be the same as in the rock from Brewery Hill, gives the following result:

Tentative mineralogical composition of quartz monzonite porphyry from Browns Gulch.

	Per cent by weight.
Quartz	25.62
Orthoclase	22.80
Albite	30.39
Anorthite	13.34
Biotite	1.89
Magnetite	2.78
Apatite	.34
Titanite	.59
Water, not used	.72
	98.47

In the course of the calculation it was found that about half of the ferrous oxide was in excess of the requirements of the mineralogical combinations used. This was calculated as magnetite. Under the same supposition as was previously made regarding the feldspar molecules, the foregoing statement becomes—

Mineralogical composition of quartz monzonite porphyry from Browns Gulch.

Quartz	25.62
Orthoclase	24.90
Andesine ($Ab_{68}An_{32}$, or near Ab_2An_1)	41.63
Biotite	1.89
Magnetite	2.78
Apatite	.34
Titanite	.59
Water, not used in calculation	.72
Unaccounted for	1.18
	99.65

This is clearly the composition of a monzonitic rock. Although a more siliceous porphyry than that of Brewery Hill, containing less biotite and no hornblende, this rock has less quartz than the other, both in the norm and in the mode.

MONZONITE PORPHYRY.

MEGASCOPIC CHARACTER.

The calcic type of porphyry, represented by the mass of monzonite porphyry forming most of Bald Mountain and the greater portions of Nigger, Prospect, and Mineral hills, is generally a fine-grained rock of dull gray or green color. Where the rock is fresh the color is dark gray; but fresh material is nowhere exposed at the surface, and some shade of green, due to the secondary minerals chlorite and epidote, is eminently characteristic of this porphyry. Ordinarily the color is dark grayish green, as may be seen along the many roads on both sides of French Gulch, west of Lincoln, or on the slopes of Bald Mountain. In underground workings, however, where the porphyry contains much finely disseminated pyrite, the tint may be much lighter. The general texture and appearance of the monzonite porphyry, as seen in hand specimens, is shown in Plate VIII.

The porphyritic texture is nowhere conspicuous, few of the phenocrysts exceeding 5 millimeters in length, and some varieties are almost aphanitic. The most common and noticeable of the porphyritic constituents is generally hornblende, but some varieties contain considerable biotite, and in a few facies this mineral is more abundant as phenocrysts than the amphibole. Both minerals in specimens collected from ordinary outcrops are as a rule lusterless and greenish in consequence of partial alteration to chlorite, epidote, and calcite. The feldspar phenocrysts,

A. ONE MILE NORTHWEST OF SUMMIT OF MINERAL HILL.

Natural size. See page 50.

B. PROSPECT HILL, 700 FEET SOUTH OF ABUNDANCE SHAFT.

Fine-grained variety, like the porphyry of the Wellington mine. Natural size. See page 55.

MONZONITE PORPHYRY.

invariably plagioclase, are uniformly small and inconspicuous and generally have the milk-white, dull appearance indicative of partial alteration. No quartz phenocrysts have been observed in this rock.

MICROSCOPICAL CHARACTER.

Under the microscope in thin section (see fig. 3 and Pl. IX, *A* and *B*) biotite on the whole appears to be fully as abundant among the phenocrysts as is hornblende. Perfectly fresh crystals are rare and the mineral, as seen in various specimens, exhibits all stages of alteration from a slight fringe of chloritization to complete replacement of the mineral by lamellar aggregates of chlorite, epidote, and calcite, like those shown in Plate X, *A* and *B*. Quartz and muscovite or sericite have also been observed as alteration products of the biotite. The fresh mineral is a normal biotite with nothing noteworthy in color or optical behavior. Rather commonly the biotite forms phenocrystic aggregates, many of which are so crowded with grains of magnetite as to be nearly opaque and are surrounded by envelopes of granular colorless augite. This change evidently took place before the rock had finally solidified. A part of the original biotite appears to have recrystallized as a biotitic aggregate while another part was transformed into magnetite, augite, and probably some orthoclase, the last crystallizing in the groundmass outside of the augitic envelope.[1] In the course of weathering the augite may be changed to calcite while the biotite still remains nearly fresh.

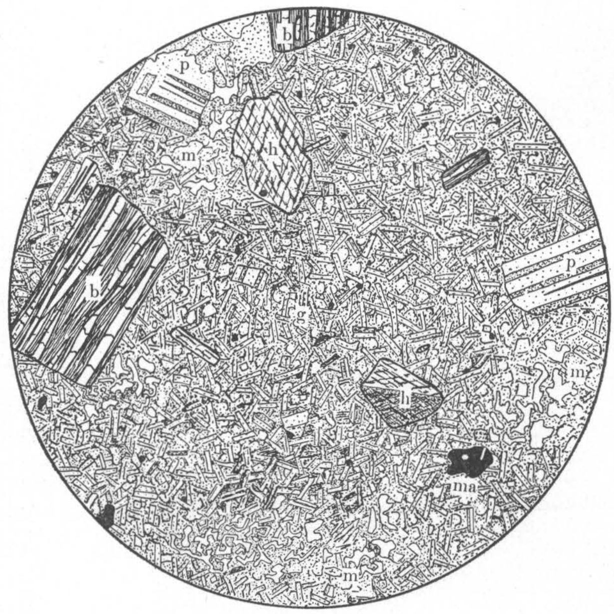


FIGURE 3.—Characteristic texture of monzonite porphyry (calcic type) as seen in thin section, with nicols crossed. × 30. Drawn by aid of the camera lucida. p, Plagioclase; b, biotite, partly altered to chlorite and epidote; h, hornblende; ma, magnetite, with small crystals of apatite; g, groundmass, chiefly plagioclase and quartz with some patches of micropegmatite, m.

The hornblende is generally some shade of brownish or yellowish green in thin section, the pleochroism being X, yellow; Y, greenish brown; and Z, brownish green to dark green. The absorption is $Y > < Z > X$. Sharp euhedral forms are rare, the crystals as a rule being more or less rounded prisms without terminal planes. Magmatic resorption with partial recrystallization of the unstable hornblende molecule has taken place in some varieties of the porphyry but not in others. Dark semiopaque rims consisting chiefly of augite and magnetite are well shown in a fresh hypersthene-bearing dioritic facies of the porphyry from the Wellington mine. (See Pl. X.) Here the inner part of the envelope, in contact with the minutely irregular surface of the unaltered hornblende crystal, is so thickly crowded with particles of magnetite as to be opaque. This layer grades outward into a semiopaque brownish layer in which granules of augite are recognizable with some difficulty. This layer in turn is covered by a thin skin of clear augite granules, nearly free from magnetite and showing an increase in size from within out. It appears from this that the change undergone by the hornblende material involves more than a single step. The dense layer of magnetite and pyroxene first formed itself undergoes some subsequent recrystallization and clarification. It is not certain, however, that this process alone proceeds so far as to produce the external envelope of clear augite. That is probably due to the reaction of calcic material from the magma with the ferruginous and magnesic constituents in the darker part of the envelope, resulting in the formation of clear augite.

[1] See Iddings, J. P., Rock minerals, New York and London, 1906, p. 425.

PLATE IX.

Photomicrographs of Fresh and Altered Monzonite Porphyry.

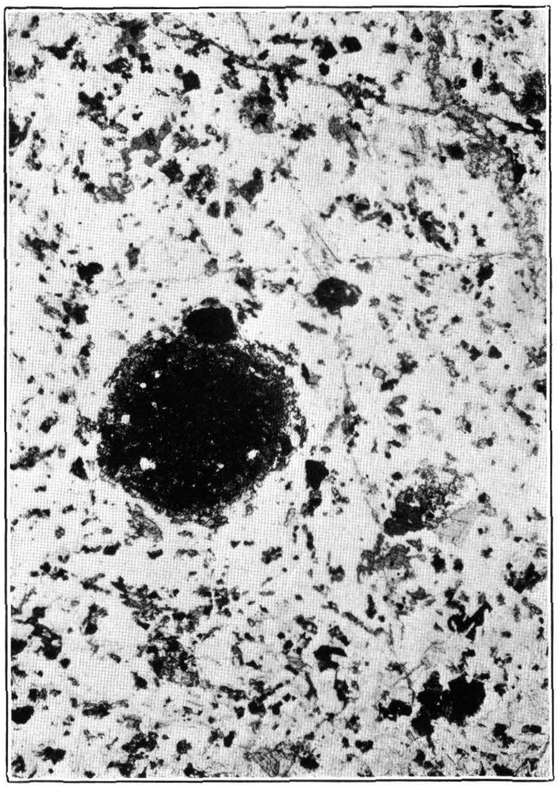
A. Monzonite porphyry, near diorite porphyry. Wellington mine. × 35.

The large rounded phenocryst is an aggregate of biotite, magnetite, and augite after hornblende. The rock is described with a chemical analysis on pages 55–56. Note the minute fissures, containing carbonate, traversing the otherwise fresh rock.

B. Same with nicols crossed.

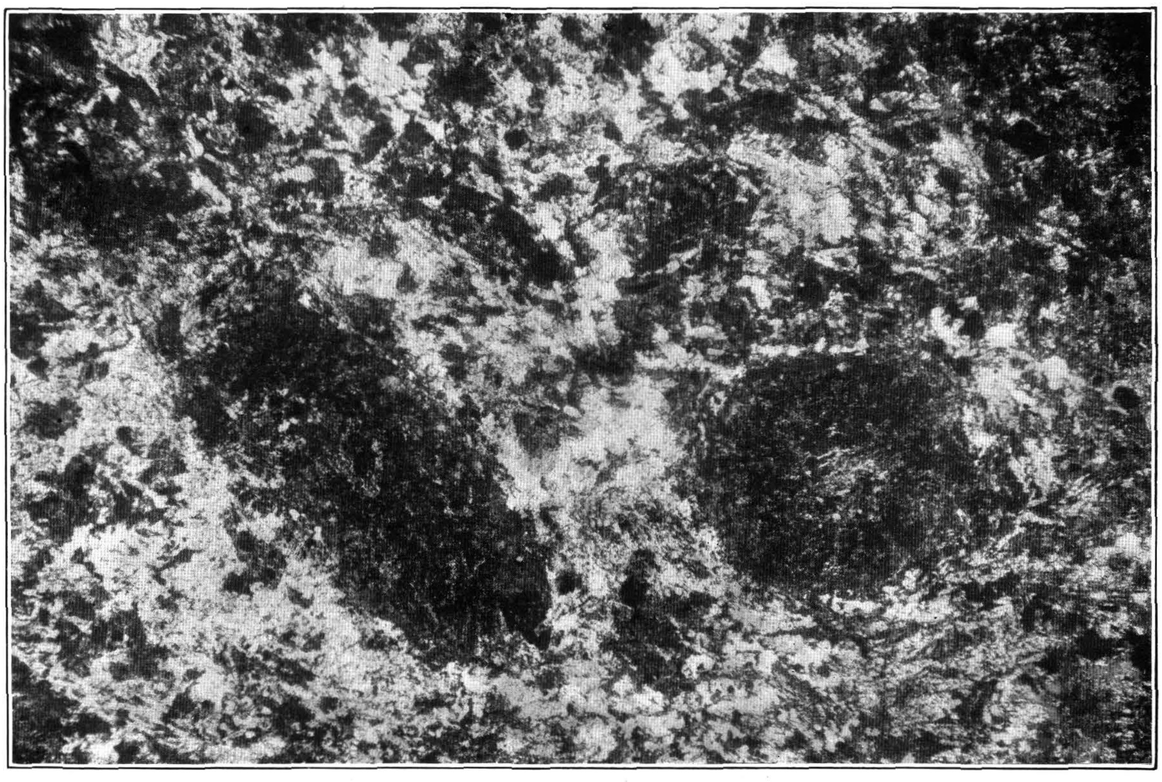
C. Same rock sericitized and carbonatized near the vein. Described on page 95, with chemical analyses.

The dark-gray areas are chiefly siderite, which refracts the transmitted light so as to appear darker than reality in the photograph. The lighter areas are quartz and sericite. × 40.



A

B.



C.

PHOTOMICROGRAPHS OF FRESH AND ALTERED MONZONITE PORPHYRY.

Entirely fresh hornblende is rare in the calcic type of porphyry. Common alteration products are chlorite, calcite, epidote, and quartz. In many specimens the former presence of hornblende is shown only by the shape of these aggregates, every particle of the original mineral having disappeared.

Minerals of the pyroxene group are but scantily represented among the phenocrysts, although a nearly colorless augite or diopside and a little hypersthene occur as microscopic phenocrysts in some of the freshest rock of the Wellington mine. Both minerals succumb readily to weathering and were probably once present in different parts of the porphyry masses where the femic constituents are now changed to chlorite, calcite, epidote, and other secondary products. The monoclinic pyroxene forms irregular anhedrons or phenocrystic aggregates. Hypersthene in some of the freshest rock of the Wellington mine forms short, stout, partly rounded prisms with the pale-green and red pleochroism characteristic of this mineral. The crystals generally show some alteration to bastite.

As a rule the phenocrysts of the femic minerals are more or less intergrown with one another. The feldspar phenocrysts of the calcic type of porphyry are all plagioclase and determinations on combined albite and Carlsbad twins give compositions varying between Ab_1An_1 and Ab_2An_3, corresponding to the part of the isomorphous feldspar series usually designated labradorite. The mineral has no special peculiarities in these rocks and except in some of the freshest specimens obtained from deep workings is more or less altered. The common decomposition products are calcite, epidote, and sericite. Kaolin is found in some thin sections, but is not abundant and its development is not a characteristic feature of the rock alteration.

The groundmass of the calcic type of porphyry is holocrystalline. The constituent crystalline grains vary so widely in shape and size that an estimate of coarseness or fineness of texture is difficult; but the average size of the grains is probably between 0.1 and 0.3 millimeter. The abundant feldspar laths give the groundmass a very different texture from that of the silicic type, as may be seen on comparing figures 2 (p. 44) and 3 (p. 51).

The minerals composing the groundmass are plagioclase (labradorite for the most part), orthoclase, quartz, biotite, augite, hypersthene, hornblende, magnetite, apatite, allanite, and zircon. The plagioclase is in general partly euhedral, but the orthoclase and quartz show no crystal outline and occupy the interstices between the plagioclase. In some thin sections the orthoclase appears as poikilitic areas. More commonly it is intergrown with quartz as micropegmatite.

As in the phenocrysts, the femic constituents of the groundmass are generally decomposed to chlorite, calcite, and epidote. Only in some of the freshest specimens obtained at a distance from the ore bodies is there any pyroxene remaining or are the biotite and hornblende entirely free from alteration.

Among the accessory minerals allanite and titanite are rare and are not present in every thin section.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The only samples of the calcic type of porphyry analyzed in the course of the present investigation were collected from the Wellington mine. These are perhaps slightly finer grained and a little more femic than the average of the rock mapped on Plate I (in pocket) as monzonite porphyry, being, in fact, diorite porphyries rather than monzonite porphyries; but they have the advantage of being almost perfectly fresh and were selected with the view to comparison with altered rock from the same mine. Inasmuch as many analyses of similar monzonite porphyries from the Leadville and Tenmile districts are available, the expenditure of additional chemical work on a thoroughly representative and of necessity more or less epidotized and chloritized specimen of the calcic type of porphyry from the Breckenridge district did not appear called for.

PLATE X.

Photomicrographs of Porphyries.

A. Quartz monzonite porphyry (intermediate variety), east slope of Mount Guyot. × 40.

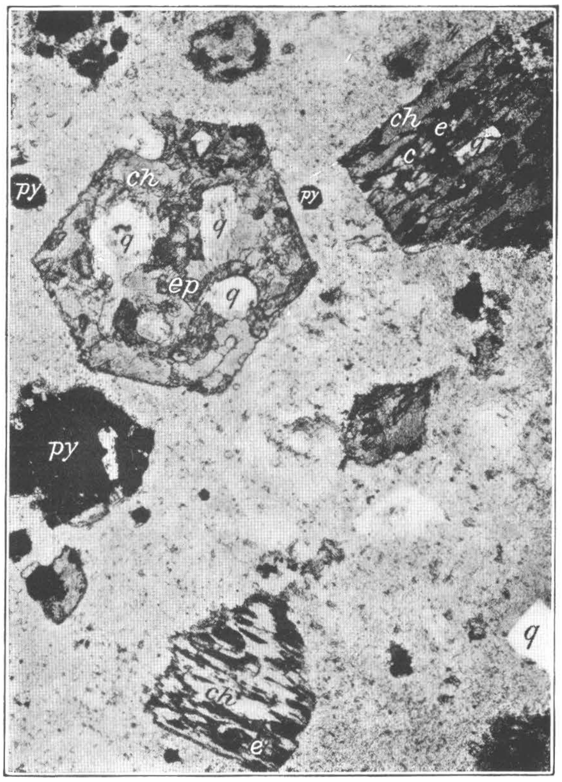
Shows porphyritic alteration. The biotite is changed to aggregates of chlorite (ch), epidote (e), calcite (c), and quartz (q). The groundmass, were the nicols crossed, would appear as a very fine mosaic of quartz and orthoclase.

B. Quartz monzonite porphyry, slope east of Hoosier Pass. × 40.

Rock is altered and contains much sericite as well as chlorite. The bent crystal of biotite, about two-thirds of which is shown, has been changed to chlorite, sericite, and calcite.

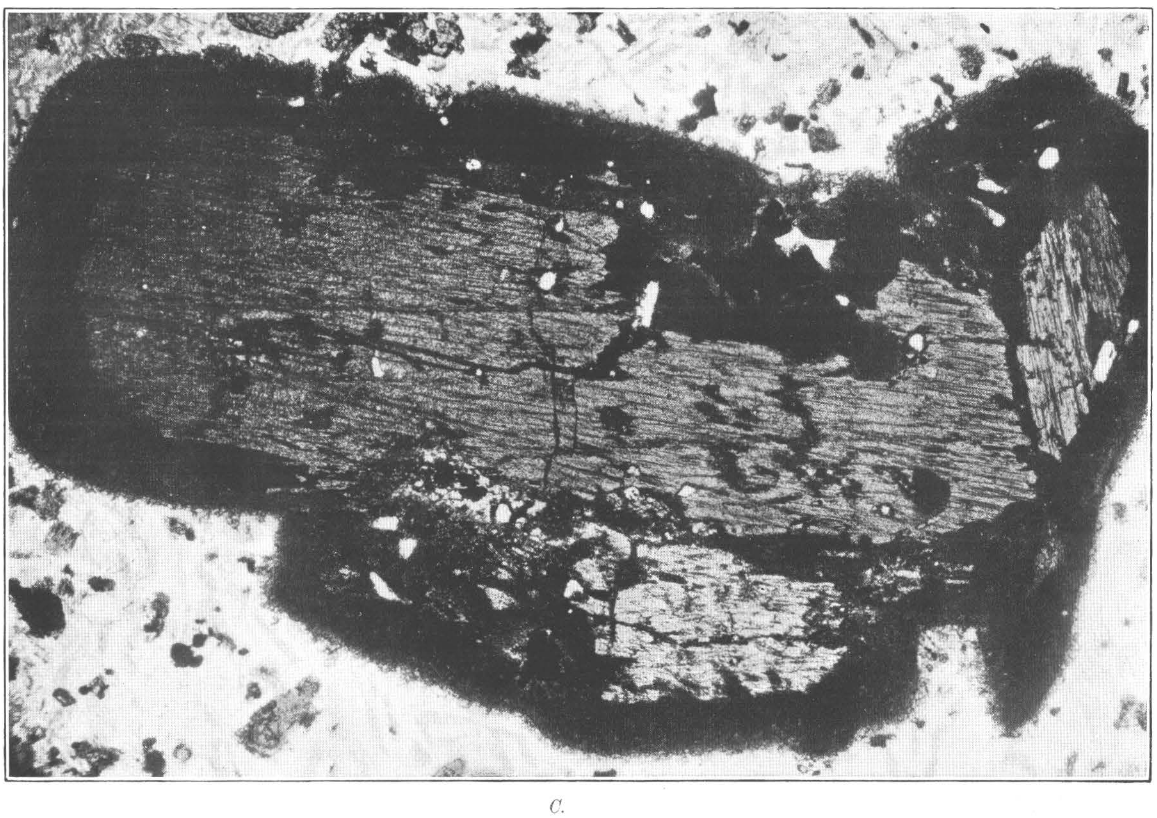
C. Monzonite porphyry, near diorite porphyry, Wellington mine. × 40. Nicols crossed.

Photograph intended particularly to show the characteristic rimming of the hornblende phenocrysts as described on page 51.



A.

B.



C.

PHOTOMICROGRAPHS OF PORPHYRIES.

The two analyses made are as follows

Chemical analyses of diorite porphyry

[W T Schaller analyst]

	1	2		1	2
SiO_2	55 44	57 35	Cr_2O_3		None
Al_2O_3	14 95	16 29	V_2O_3		Trace
Fe_2O_3	4 37	3 15	NiO		None
FeO	5 18	4 36	MnO	0 22	0 12
MgO	3 58	2 41	BaO	16	10
CaO	6 12	5 66	SrO	04	05
Na_2O	4 44	4 50	LiO	None	None
K_2O	2 83	3 39	ZnO		None
H_2O-	12	15	Rare earths		None
H_2O+	84	70			
TiO_2	1 22	1 07		100 44	100 55
ZrO_2	None	Trace			
CO_2	35	46	Specific gravity of rock mass	2 82	2 763
P_2O_5	49	70	Specific gravity of rock powder at 25 C	2 863	2 799
FeS_2	09	09			

1 Diorite porphyry Andose (Br 51) Wellington mine dump of Extenuate tunnel
2 Diorite porphyry Andose (Br 217) Wellington mine northeast end of Oro level

The sample used for analysis No 1 is a hard, fresh dark-gray rock of splintery fracture, with glistening, black, prismatic phenocrysts of hornblende up to about 5 millimeters in diameter As it was collected from the mine dump its exact locality is not certainly known, but it probably came from a crosscut, about 50 feet long, that runs northwest from the end of the drift on the Spur vein on the Extenuate level (See Pl XXVIII, p 130) This crosscut is all in fresh, hard country rock like the specimen

Under the microscope the phenocrysts of hornblende are seen to be accompanied by smaller phenocrysts of plagioclase, pale augite or diopside, hypersthene, biotite, magnetite, and apatite Hornblende is the only mineral that is distinctively and solely a porphyritic constituent The others occur also in the groundmass and such is the gradation in size that no definite distinction of groundmass from phenocrysts is possible, in other words, the rock has a seriate porphyritic fabric [1] The preponderant constituents of the groundmass are lath-shaped plagioclases With these are intersertal quartz and orthoclase, in part micrographically intergrown, and some intersertal grains of the femic minerals The hornblende is of the ordinary brownish-green variety and is noteworthy only for the well-developed reaction rims described on page 51 and illustrated in Plate X, *C* (p 54) The hypersthene, in stout subhedral prisms up to about a millimeter in length, is distinctly pleochroic in the usual faint red and green tints Biotite is not abundant and occurs as tiny anhedral flakes, many of which are intergrown with the pyroxenes The plagioclase is fresh and clear Most of it is between Ab_1An_1 and Ab_2An_3 in composition The orthoclase is anhedral, generally rather turbid, and is not a conspicuous constituent A little zircon is present, but no allanite was seen

The norm of the rock is as follows

Norm of diorite porphyry (Br 51) from Wellington mine

Quartz	3 00
Orthoclase	16 68
Albite	37 20
Anorthite	12 51
Diopside	12 33
Hypersthene	6 81
Magnetite	6 26
Ilmenite	2 28
Apatite	1 01
Pyrite	09
	98 17
Water	96
CO_2	35
	99 48

[1] Iddings J P Igneous rocks vol 1 New York and London 1909 p 197

According to this norm and the chemical analysis the rock is dosalic, perfelic, alkalicalcic, and dosodic. It is therefore andose.

The presence together of diopside, hypersthene, hornblende, and biotite, the composition of none of which is accurately known, renders calculation of the mode from the chemical analysis impracticable. In the actual rock part of the potash in the orthoclase of the norm must be combined in biotite and part of the lime in the normative diopside must be in the plagioclase, which is certainly more calcic than the Ab_3An_1 of the norm, optical determination on some of the albite Carlsbad twins giving $Ab_{40}An_{60}$ with maximum extinction angles of at least 36° in sections normal to (010). The norm sufficiently expresses the mineralogical composition of the rock to show that the ratio of orthoclase to plagioclase is less than that in typical monzonite. Consequently, although mapped with the monzonite porphyry of which it is an inseparable facies, this rock is petrographically a diorite porphyry.

The rock of analysis No. 2 was selected for the particular purpose of comparison with altered varieties near by, as is shown on page 95. It is a dark-gray, compact, splintery rock with a few dull-black phenocrysts of hornblende in a nearly aphanitic groundmass. Under the microscope the apparent phenocrysts of hornblende are seen to be completely changed to aggregates of biotite crowded with particles of magnetite. These pseudomorphous phenocrysts, few of which exceed 3 millimeters in length, are sparsely distributed through a groundmass consisting of a felted aggregate of subhedral to lath-shaped plagioclase with many small irregular flecks of biotite; with diopside in minute rounded prisms and larger anhedrons; with a good deal of clear interstitial orthoclase; with a little interstitial quartz; and with grains of magnetite and small prisms of apatite. The plagioclase is mostly labradorite, crystals tested being near Ab_2An_3 in composition, a fact which indicates that only a part of the soda is in this mineral. Although the constituents of the rock are generally quite fresh, there is some carbonate, probably near siderite, present in microscopic cracks and in little bunches here and there where these cracks traverse minerals particularly susceptible to carbonatization. The pseudomorphs of biotite and magnetite after hornblende are generally surrounded by a little halo of this carbonate, which, as the chemical analysis indicates, composes about 1 per cent of the rock.

The norm of this diorite porphyry is as follows:

Norm of diorite porphyry (Br. 217) from the Oro level of the Wellington mine.

Quartz	4.50
Orthoclase	20.02
Albite	37.73
Anorthite	14.18
Diopside	8.41
Hypersthene	5.61
Magnetite	4.41
Apatite	1.34
Ilmenite	1.98
Pyrite	.09
	98.27
Water, etc., not used	1.46
	99.73

This norm, like that on page 55, corresponds to andose. Both norms are much alike, but it is noteworthy that while the one rock actually contains hypersthene the other, so far as the study of one thin section shows, does not.

AN EXCEPTIONAL FACIES.

A porphyry differing from any other observed in the district forms a small north-south dike on the steep spur east of Monitor Gulch, near Farncomb Hill. It is dark gray, with phenocrysts of plagioclase up to 5 millimeters in length and smaller ones of biotite, in an aphanitic groundmass. The microscope shows phenocrysts of clear andesine (near Ab_1An_1) and fresh biotite in a fine-grained feldspathic groundmass that contains a good deal of secondary calcite and is chiefly remarkable for the abundant occurrence of biotite in wispy aggregates of very minute scales. These are distributed all through the groundmass and form little fringes or shells around the phenocrysts of the same mineral. Some of the aggregates have a form suggestive of pseudomorphous development after hornblende and the general habit of the mineral and its association with calcite are indicative of secondary origin. Biotite has been reported as an alteration product of olivine but is not one of the minerals ordinarily arising from rock decomposition. Unfortunately the Monitor Gulch rock does not furnish quite conclusive evidence that the mineral is secondary. The rock is a dioritic or andesitic porphyry belonging probably to the calcic division of the Breckenridge porphyries.

QUARTZ MONZONITE PORPHYRY (INTERMEDIATE TYPE).

DISTRIBUTION.

The intermediate type of porphyry has not been separately mapped on Plate I (in pocket). The reason for this is that porphyry of distinctly intermediate character forms no large masses within the area specially studied. Moreover, this type, if type it can be called, possesses no characteristic property so readily recognizable that consistent discrimination over the whole field would be possible without much more elaborate chemical and petrographic work than the prospective results would justify. The texture and appearance of some of the intermediate porphyry are shown in Plate XI.

The intermediate variety is best exemplified by the thick sheet that forms the upper part of Mount Guyot, just east of the head of French Gulch and outside of the area mapped. Other occurrences are some intrusive sheets east of Hoosier Pass, 8 miles south of Breckenridge. Part of the mass mapped as monzonite porphyry at the mouth of Gibson Gulch, a mile east-northeast of Breckenridge, is of intermediate character, as is also some material thrown out from a shaft in the Mekka placer, on the south side of French Gulch. On the upper Swan a dike (shown in Plate I) just south of Snyder's camp and bench mark 9823 is composed of the intermediate variety, which forms a considerable mass also near the mouth of the middle Swan east of Georgia Gulch and outside of the mapped area. The porphyry on the west slope of Gibson Hill and that exposed along the railway between Rocky Point and Bacon have some intermediate characteristics but have been classed with the silicic type.

MEGASCOPIC FEATURES OF THE PORPHYRY OF MOUNT GUYOT.

The rock of Mount Guyot was studied on the east slope of the peak, from Georgia Pass to the summit. In Georgia Pass the pre-Cambrian rocks and a little mass of disturbed, much indurated dark shale and some quartzite are cut by dikes of a fresh dark-gray hornblendic porphyry which the microscope shows to be a rather femic variety of the calcic type. It is a diorite porphyry with unusually abundant augite (or diopside) in the groundmass. These dikes appear to be offshoots from the main Guyot mass of porphyry and to represent a femic marginal facies of that rock. As the slope west of the pass is ascended, the prevalent variety of the porphyry is first a light-gray rock showing small phenocrysts of plagioclase and biotite and suggesting in the presence of hornblende and in the absence of noticeable quartz phenocrysts the calcic rather than the silicic type of porphyry. The average size of grain is apparently about 3 millimeters. The microscope, however, reveals unexpected resemblances to the siliceous quartz monzonite porphyry. The thin sections show abundant subhedral to euhedral phenocrysts of plagioclase, biotite, and hornblende, with some rounded phenocrysts of quartz and grains of magnetite in a very fine granular quartz-orthoclase groundmass such as is found in the silicic type of porphyry. The plagioclase, as determined by extinctions of albite-Carlsbad twins, maximum extinctions in the zone perpendicular to (010), and the mean index of refraction, is near Ab_1An_1. The greenish yellow hornblende has the pleochroism X greenish yellow, Y yellowish green, and Z deep grass green. The absorption is $Y > < Z > X$. The biotite is the usual kind present in these rocks. Small prisms of apatite are fairly abundant, but no allanite was detected in the single section examined. The secondary minerals, sparingly present, are epidote and chlorite.

Toward the summit of the peak the porphyry on the whole (see Pl. XI) shows a scarcely perceptible gradation to a more equally granular rock, becoming at the top of the peak virtually a fine-grained quartz monzonite with the light-gray, very slightly reddish tint, common to these plagioclase-orthoclase rocks.

MICROSCOPICAL FEATURES OF THE PORPHYRY OF MOUNT GUYOT.

A thin section of the rock from the summit of Mount Guyot shows the texture illustrated in figure 4. Although some of the plagioclase has a porphyritic development, the distinction between phenocrysts and groundmass is almost lost, and the rock has nearly the equigranular texture of a plutonic mass.

The constituents, which are almost ideally fresh, are plagioclase whose composition (Ab_1An_1) is on the line between andesine and labradorite, orthoclase, quartz, biotite, and hornblende in part intergrown, titanite, apatite, and magnetite. No allanite was seen in the thin section studied.

FIGURE 4.—Coarsely crystalline quartz monzonite porphyry (intermediate type), from the summit of Mount Guyot, as seen in thin section with nicols crossed. × 30. Drawn with camera lucida. Texture nearly equigranular. p, Plagioclase; q, quartz; or, orthoclase; b, biotite.

The plagioclase is fresh, and as it is sharply twinned according to the albite, Carlsbad, and pericline laws without much zonal structure, its character is closely determinable by optical means. My own determinations gave as an average $Ab_{58}An_{42}$. Mr. F. C. Calkins kindly made some check determinations which gave a ratio of $Ab_{60}An_{40}$. The feldspar is thus virtually Ab_3An_2, or andesine. Where the crystals are zoned, the composition may range from $Ab_{80}An_{20}$ to $Ab_{49}An_{51}$. The form of the plagioclase is subhedral to euhedral. The orthoclase and quartz are entirely anhedral and tend to be interstitial with reference to the plagioclase. The orthoclase, although fresh, shows the usual dusty turbidity of that mineral, and some of it contains a little perthitic albite. The biotite and hornblende differ in no way from the occurrences of these two minerals in the other porphyries already described.

CHEMICAL COMPOSITION AND CLASSIFICATION OF THE PORPHYRY OF MOUNT GUYOT.

The chemical composition of the porphyry from the top of Mount Guyot is as follows:

Chemical analysis of quartz monzonite porphyry from the summit of Mount Guyot.

[R. C. Wells, analyst.]

SiO_2	64.28	P_2O_5	0.32
Al_2O_3	16.99	F	.06
Fe_2O_3	2.59	S	None.
FeO	2.64	V_2O_3	.03
MgO	1.13	NiO	None.
CaO	3.95	MnO	.14
Na_2O	3.78	BaO	.10
K_2O	3.51	SrO	.04
H_2O-	.07	Li_2O	None.
H_2O+	.25		
TiO_2	.49		100.38
ZrO_2	.01		

The norm calculated from this analysis is as follows:

Norm of quartz monzonite porphyry from the summit of Mount Guyot.

	Per cent by weight.
Quartz	18. 31
Orthoclase	20. 57
Albite	31. 96
Anorthite	17. 79
Corundum	. 51
Hypersthene	5. 04
Apatite	. 67
Ilmenite	. 91
Magnetite	3. 71
	99. 47
Water	. 32
	99. 79

Consequently in the American quantitative classification the rock is persalic, quardofelic, alkalicalcic, sodipotassic but very near dosodic, and is therefore amiatose, near yellowstonose.

The mode may be calculated with the same data as regards the hornblende and biotite that were used on page 47 for the porphyry of Brewery Hill. This gives the following result:

Tentative composition of quartz monzonite porphyry from the summit of Mount Guyot.

	Per cent by weight.
Quartz	20. 74
Orthoclase	16. 17
Albite	32. 07
Anorthite	15. 88
Biotite	8. 16
Hornblende	1. 95
Apatite	. 67
Titanite	. 59
Magnetite	3. 25
	99. 48

In the light of the microscopical study the foregoing may be rearranged as follows:

Mineralogical composition of quartz monzonite porphyry from the summit of Mount Guyot.

	Per cent by weight.
Quartz	20. 74
Orthoclase (with $29K_2O$ and $18Na_2O$)	25. 63
Andesine (Ab_3An_2)	38. 49
Biotite	8. 16
Hornblende	1. 95
Apatite	. 67
Titanite	. 59
Magnetite	3. 25
	99. 48

This calculation, which is probably very close to the actual composition of the rock, shows that the orthoclase contains a considerable quantity of the albite molecule and suggests that in the calculated compositions on pages 48 and 50, an additional part of the albite should be transferred from the plagioclase to the alkali feldspar.

OTHER FACIES.

The rock referred to on page 57 as occurring near the mouth of Gibson Gulch, and belonging probably with the intermediate division of the porphyries, is apparently merely a local facies of the calcic variety. As exposed at the mouth of the Johannesburg tunnel this is a light-gray, fine-granular rock in which are visible a very few small phenocrysts of hornblende. Under the microscope the general texture is seen to be subhedral granular and, although finer, resembles that of the Mount Guyot rock. The mineral constituents of the two are the same.

The material thrown out from the prospect shaft in the Mekka or Sisler placer is of two kinds. One is a fresh porphyry of the silicic type in which unusually numerous phenocrysts of andesine, quartz, orthoclase, and biotite are distinctly separable from a microgranular groundmass of orthoclase and quartz having an average diameter of grain of about 0.1 millimeter. Small crystals of allanite, some sharply euhedral and twinned, are fairly abundant. This porphyry, which appears to be the general bedrock of the placer, is generally similar to the rock analyzed and described from Brewery Hill (pp. 45–48.) The rock associated with it, exactly in what relation is not known, is darker, is not noticeably porphyritic, and contains unusually abundant biotite. Under the microscope it shows a subhedral granular texture, the average diameter of grain being about 1 millimeter. The constituents are andesine ($Ab_{53}An_{47}$), quartz, biotite, hornblende, magnetite, apatite, and zircon. Quartz is abundant. It fills interstices between and in part incloses the subhedral plagioclase. The most noteworthy feature of the rock is the absence of orthoclase, which in this district is almost invariably present in the porphyries even in those in which quartz is less abundant than in this facies, where the potassium apparently has gone into biotite instead of into alkali feldspar. The rock is a quartz-mica diorite.

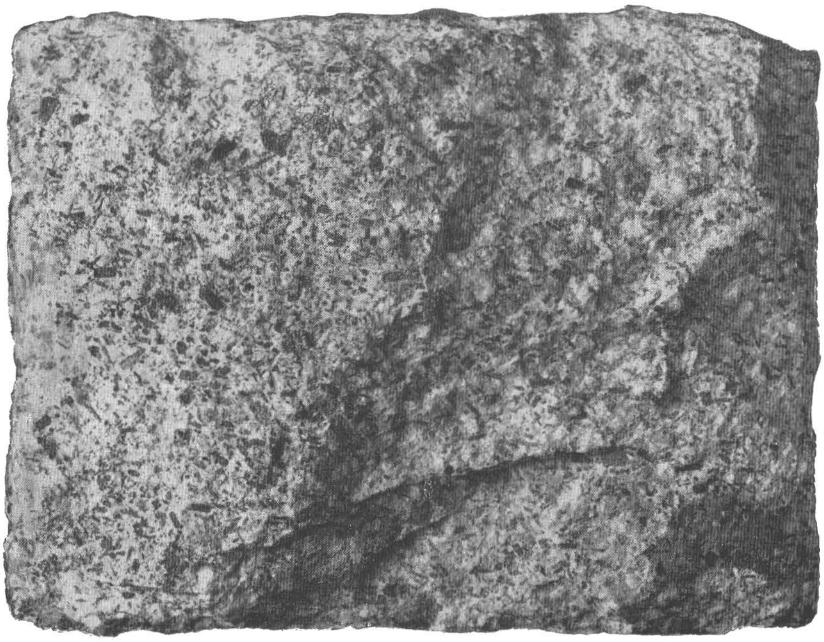
Another rock deserving mention, although it is not within the area mapped, is that of the intrusive mass that is cut through by the middle fork of the Swan, near its mouth. This is a fine-grained fresh pinkish-gray porphyry, with small sparse phenocrysts of hornblende and biotite, which in general appearance much resembles the variety from the mouth of Gibson Gulch, the similarity extending also to microscopical features. Save for the occasional phenocrysts mentioned, which do not appear in every thin section, the rock is subhedral granular. The constituents are andesine ($Ab_{60}An_{40}$–$Ab_{55}An_{45}$, with more sodic peripheral zones in some crystals), orthoclase, quartz, biotite, hornblende, diopside, magnetite, and apatite. The hornblende is intergrown with biotite and pyroxene, the pyroxene in such case forming the kernel of the crystal. The quartz and orthoclase are anhedral and are largely interstitial with reference to the plagioclase. This rock is so inconspicuously porphyritic that it is virtually a fine-grained quartz monzonite.

RELATIONS OF THE PORPHYRIES TO ONE ANOTHER.

The foregoing descriptions have made fairly clear the fact that all the porphyries of the district are closely related and that the types recognized correspond to parts of a generally continuous series. This is well brought out by the accompanying table, in which are assembled all the available chemical analyses of the comparatively fresh porphyries of the Leadville, Tenmile, and Breckenridge districts. The same general relationship is displayed graphically by the variation diagram of figure 5, constructed from the analyses in the table by plotting the molecular porportions of the principal constituents. In detail, however, the diagram shows that the proportions of the different constituents vary in an irregular way, analyses showing nearly the same silica, for example, exhibiting wide divergence in other constituents, so that the more closely spaced the analyses along the silica abscissas the more irregular appear the curves connecting the ordinates of each base. Thus, it can not be said that the series of analyses represents uniform change in composition according to any simple set of laws. For example, a constituent neither increases regularly as another decreases nor closely parallels another in its variations from one rock facies to another. The most that can be said is that alumina and the alkalies remain fairly constant, with soda always in excess of potash, and that lime, magnesia, and the iron oxides generally decrease with increase of silica. While the rocks analyzed are undoubtedly closely related as regards their magmatic derivation, their variations have not the simple character to be expected in samples taken along a single cross section of one well-differentiated igneous mass.

In the table the molecular ratios of the main constituents are given below the percentage figures.

A. SUMMIT OF MOUNT GUYOT.
Natural size. Described with chemical analyses on pages 57–59.



B. RIDGE 2 MILES SOUTHWEST OF BOREAS.
Natural size. See page 57.

QUARTZ MONZONITE PORPHYRY, INTERMEDIATE VARIETIES

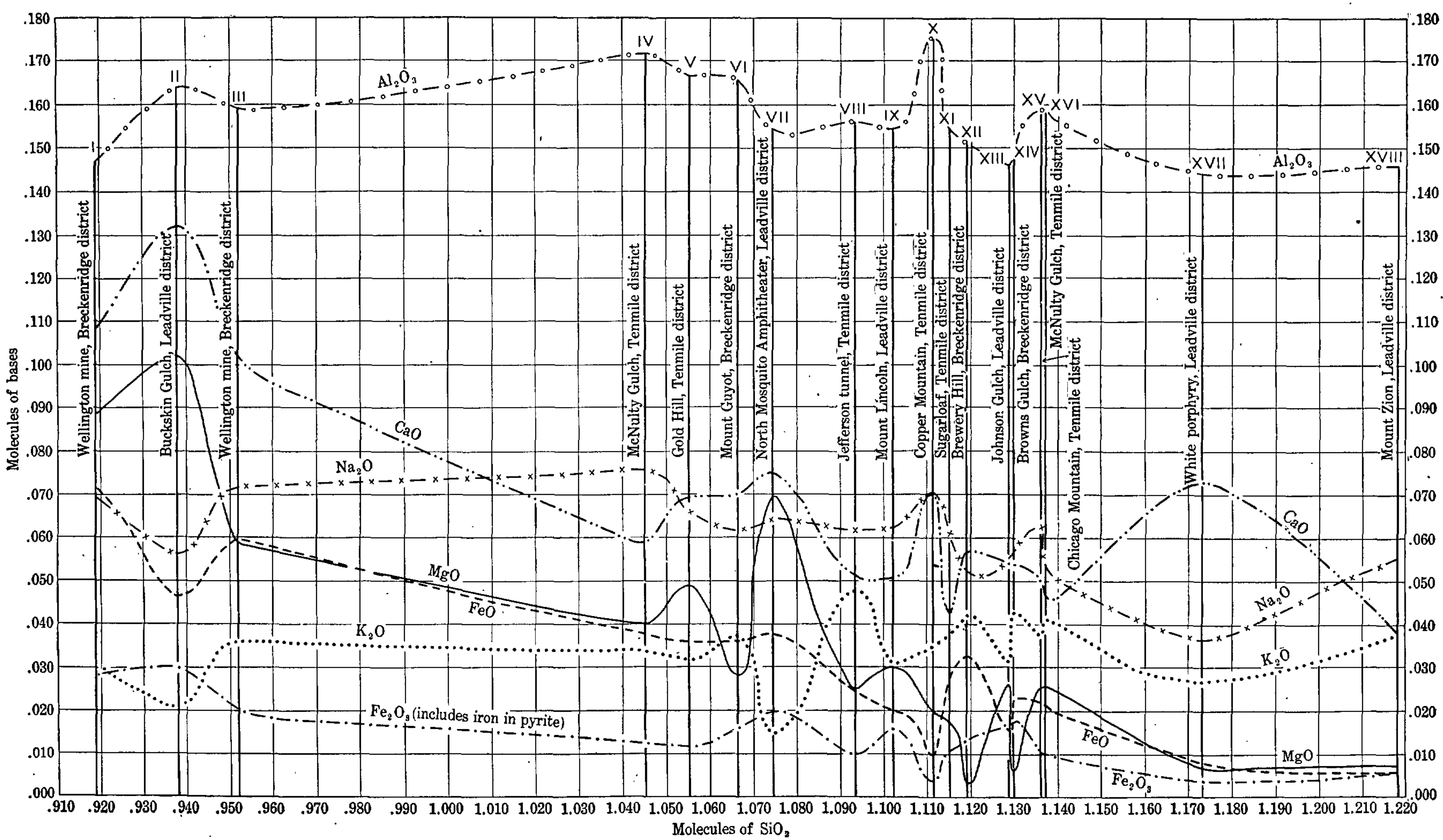


FIGURE 5.—Diagram showing variation of molecular constituents in 18 intrusive rocks of the Breckenridge, Tenmile, and Leadville districts.

Analyses of porphyritic intrusive rocks of the Breckenridge and neighboring districts.

	1[a]	2	3[a]	4	5	6[a]	7	8	9	10	11	12[a]	13	14[a]	15	16	17	18
SiO_2	55.44	56.62	57.35	63.02	63.66	64.28	64.81	65.94	66.45	67.01	67.29	67.53	68.10	68.14	68.30	68.60	70.74	73.50
	.919	.938	.951	1.045	1.055	1.066	1.074	1.093	1.102	1.111	1.115	1.120	1.129	1.130	1.136	1.137	1.173	1.218
Al_2O_3	14.95	16.74	16.29	17.61	17.05	16.99	15.73	16.00	15.84	18.03	15.78	15.46	14.97	15.29	16.24	16.21	14.68	14.87
	.146	.164	.159	.172	.167	.167	.154	.156	.155	.176	.154	.151	.146	.150	.159	.158	.144	.146
Fe_2O_3	4.37	4.94	3.15	1.78	1.97	2.59	1.68	.60	2.59	.66	1.86	2.18	2.78	.35	1.60	1.67	.69	.95
	.027	.030	.019	.011	.012	.016	.010	.003	.016	.004	.011	.014	.017	.002	.010	.010	.004	.006
FeO	5.18	3.27	4.36	2.76	2.62	2.64	2.91	1.74	1.43	.72	1.97	2.42	1.10	1.66	1.63	1.57	.58	.42
	.072	.046	.060	.038	.036	.037	.040	.024	.020	.010	.028	.033	.015	.023	.022	.021	.008	.006
MgO	3.58	4.08	2.41	1.63	1.99	1.13	2.82	1.02	1.21	.84	.72	.16	1.10	.26	1.05	1.05	.28	.29
	.088	.102	.059	.040	.049	.028	.070	.025	.030	.020	.018	.004	.027	.006	.026	.026	.007	.007
CaO	6.12	7.39	5.66	3.30	3.89	3.95	4.22	2.87	2.90	3.99	2.36	3.24	3.04	3.03	2.79	2.61	4.12	2.14
	.109	.132	.101	.059	.069	.070	.075	.051	.051	.071	.042	.058	.054	.054	.050	.046	.073	.038
Na_2O	4.44	3.50	4.50	4.72	4.13	3.78	3.98	3.85	3.92	4.42	3.77	3.24	3.46	3.59	3.90	3.29	2.29	3.46
	.071	.056	.072	.076	.066	.061	.064	.062	.063	.071	.061	.052	.055	.058	.063	.053	.037	.056
K_2O	2.83	1.97	3.39	3.23	3.09	3.51	1.43	4.56	2.89	3.53	3.55	3.86	2.93	4.07	3.52	3.88	2.59	3.56
	.030	.021	.036	.034	.032	.037	.015	.048	.031	.037	.038	.041	.031	.043	.037	.041	.027	.038
H_2O	.96	.92	.85	2.03	1.19	.32	.62	1.13	.84	.91	2.10	.78	1.28	.79	1.71	.92	2.09	.90
TiO_2	1.22		1.07			.49	.08		.10			.41	.07	.36				
	.015					.006			.001									
ZrO_2	None.		Trace.								None.	.02		.01				
CO_2	.35	1.15	.46				1.08	1.55	1.35			.03	.92	.22		.19	2.14	
P_2O_5	.49	Trace.	.70	.16	.27	.32	.23	.23	.36	.10	.28	.01	.16	.17	.13	.21		None.
	.003					.002			.002		.002							
Cl						F .06	.04	.03	.05			F .03	.03			.03	Trace.	
						.003												
FeS_2	.09		.09				.90	.60				.09		1.52				
MnO	.22	.15	.12	Trace.	.14	.14	.08	.14	.09	.09	.21	.10	.09	.12	.12	.09	.06	.03
	.003					.002			.001		.003							
BaO	.16		.10	.08		.10				.10	None.	.07		.03	Trace.		.03	
	.001																	
SrO	.04	Trace.	.05		.08	.04	Trace.	Trace.	.07			None.	.08			Trace.	Trace.	Trace.
	100.44	100.73	[b] 100.55	100.32	100.08	[c] 100.38	100.61	100.26	[d] 100.09	100.40	100.16	99.63	100.11	[e] 99.65	100.03	100.32	100.29	100.12
Sp. gr.	2.827	2.768 at 16° C.	2.763	2.689 at 16.5° C.			2.740 at 16° C.	2.672 at 21° C.	2.670 at 16° C.	2.606 at 26° C.			2.736 at 16° C.			2.640 at 27° C.	2.680 at 16° C.	

[a] Analyses made for this report. [b] Trace of V_2O_3. [c] 0.03 V_2O_3. [d] Trace Li_2O. [e] 0.01 NiO.

1. Diorite porphyry (Br. 51). *Andose.* Wellington mine, Breckenridge district. W. T. Schaller, analyst.

2. "Hornblende-mica porphyrite." *Andose.* Buckskin Gulch, Leadville district. W. F. Hillebrand, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 340; Washington, H. S., Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 276, No. 36; Clarke, F. W., Bull. U. S. Geol. Survey No. 419, 1910, p. 109, column F.

3. Diorite porphyry (Br. 217). *Andose.* Wellington mine, Breckenridge district. W. T. Schaller, analyst.

4. "Diorite porphyry," McNulty type. *Lassenose.* Tenmile district. L. B. Eakins, analyst. References: Washington, H. S., op. cit., p. 174, No. 25; Clarke, F. W., op. cit., p. 110, column E.

5. "Quartz-hornblende-mica porphyrite." *Yellowstonose.* Gold Hill, Tenmile district. W. F. Hillebrand, analyst. References: Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 227; Washington, H. S., op. cit., p. 186, No. 20; Clarke, F. W., op. cit., p. 110, column A.

6. Quartz monzonite porphyry (Br. 177). *Amiatose* near *yellowstonose.* Summit of Mount Guyot, Breckenridge district. R. C. Wells, analyst.

7. "Biotite porphyrite." *Tonalose.* North Mosquito Amphitheater, Leadville district. W. F. Hillebrand, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 340; Washington, H. S., op. cit., p. 232, No. 22; Clarke, F. W., op. cit., p. 109, column G.

8. "Granite porphyry." *Toscanose.* Jefferson tunnel, Tenmile district. W. F. Hillebrand, analyst. References: Washington, H. S., op. cit., p. 162, No. 40; Clarke, F. W., op. cit., p. 110, column B in lower table.

9. "Lincoln porphyry." *Lassenose.* Summit of Mount Lincoln, Leadville district. W. F. Hillebrand, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 332; Washington, H. S., op. cit., p. 174, No. 24; Clarke, F. W., op. cit., p. 108, column C,

10. "Diorite porphyry." *Yellowstonose.* Copper Mountain, Tenmile district. L. B. Eakins, analyst. References: Washington, H. S., op. cit., p. 186, No. 19; Clarke, F. W., op. cit., p. 110, column D.

11. "Quartz porphyrite." *Toscanose.* Sugarloaf, Tenmile district. L. G. Eakins, analyst. References: Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 227; Washington, H. S., op. cit., p. 162, No. 38; Clarke, F. W., op. cit., p. 110, column B in upper table.

12. Quartz monzonite porphyry (Br. 104). *Amiatose* near *toscanose.* Northeast slope of Brewery Hill, Breckenridge district. R. C. Wells, analyst.

13. "Gray porphyry." *Yellowstonose.* Johnson Gulch, Leadville district. W. F. Hillebrand, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 332; Washington, H. S., op. cit., p. 186, No. 18; Clarke, F. W., op. cit., p. 109, column D.

14. Quartz monzonite porphyry (Br. 110). *Toscanose.* Mouth of Browns Gulch, Breckenridge district. R. C. Wells, analyst.

15. "Quartz monzonite." *Lassenose.* Chicago Mountain, Tenmile district. W. F. Hillebrand, analyst. References: Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 227; Washington, H. S., op. cit., p. 176, No. 28; Clarke, F. W., op. cit., p. 110, column C of upper table.

16. "Granite porphyry." *Toscanose.* McNulty Gulch, Tenmile district. W. F. Hillebrand, analyst. References: Washington, H. S., op. cit., p. 162, No. 39; Clarke, F. W., op. cit., p. 110, column A.

17. "White porphyry" (not fresh). *Riesenose.* California Gulch, Leadville district. W. F. Hillebrand, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 326; Washington, H. S., op. cit., p. 139, No. 1; Clarke, F. W., op. cit., p. 108, column B.

18. "Mount Zion porphyry." *Toscanose.* Prospect Mountain, Leadville district. L. G. Eakins, analyst. References: Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 326; Washington, H. S., op. cit., p. 162, No. 37; Clarke, F. W., op. cit., p. 108, column A.

CHAPTER IV.

STRUCTURE OF THE DISTRICT.

BROAD FEATURES.

In the latitude of Breckenridge the generally unmetamorphosed sediments, chiefly Cretaceous, and the associated intrusive porphyries, probably of Tertiary age, form a north-south belt from 8 to 10 miles wide, bounded on the east by the pre-Cambrian rocks of the Front Range and on the west by the same ancient terrane, as exposed along the Tenmile Range. The rocks of this meridional belt, although much disturbed, have on the whole an easterly dip, and the general structure is accordingly monoclinal, the basal sediments on the west lapping up on the east slope of the Tenmile axis and the whole series on the east being faulted down against the pre-Cambrian crystalline rocks, toward which they prevailingly dip.

This dominant feature of the structure is illustrated diagrammatically in the simplest way and without any attempt at fidelity to scale in figure 6. The actual relations, as will presently be seen, have far greater complexity than is suggested by so crude a diagram.

Sedimentary beds occur on the west side of the Tenmile Range, and a consideration of the relations of these beds to those of the Breckenridge belt shows that the latter are merely part of a wider tectonic block or unit whose western boundary is the Mosquito fault, described by S. F. Emmons in the Tenmile folio.[1] From the Mosquito fault (shown in fig. 7) to Georgia Pass, where the sediments and porphyries of the Breckenridge belt are succeeded eastward by pre-Cambrian rocks, the distance is from 12 to 13 miles. Evidently the sediments of the Breckenridge area once extended across the line of the present Tenmile Range and were continuous with those of the Tenmile district. Whether, prior to their erosion, the beds swept uninterruptedly up over what is now the crest of the range until they reached the Mosquito fault, or whether they were stepped down by intervening faults, has not been determined. The Breckenridge block as a whole has been tilted to the east through an angle of about 20°, so that along its eastern edge the Upper Cretaceous shale has been brought down to juxtaposition with the pre-Cambrian, and on the west the basal beds of the sedimentary series outcrop along the east flank of the Tenmile Range, from whose higher slopes erosion has stripped them away. The eastern slope of that range, although scored by ravines and scalloped by glacial cirques, has not lost all resemblance to the old surface upon which the sediments were deposited, as may be seen on looking along the mountains from any commanding point on their flank. This feature is especially noticeable in views toward Hoosier Pass from the vicinity of Breckenridge, such as those shown in Plates IV, *B* (p. 18), and XIV, *A* (p. 70), for in these the bedding of the sediments (not apparent in the illustrations) is seen to lie at approximately the same angle as the long even slope on the pre-Cambrian rocks to the right. On Quandary Peak and on the North Star Mountains, also, are remnants of the "Sawatch" quartzite, which by their position show a close correspondence between the old sea floor upon which they accumulated and the general east slope of the Tenmile Range.

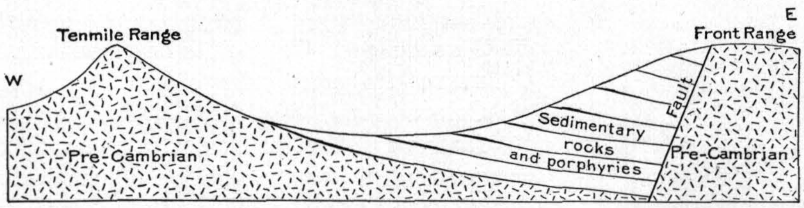


FIGURE 6.—Diagram illustrating the general structure of the tectonic belt in which Breckenridge lies.

[1] Tenmile district special folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

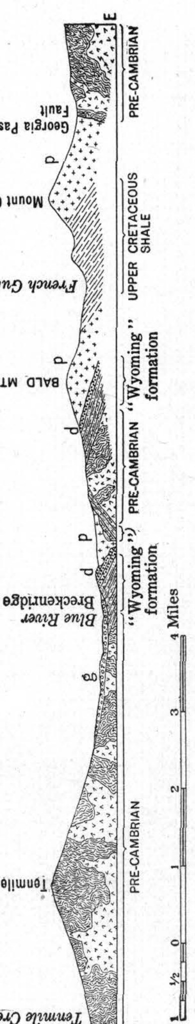


FIGURE 7.—Generalized section across the Breckenridge region, Colorado. By F. L. Ransome. Structure west of the Tenmile Range after S. F. Emmons, in Tenmile folio. p, Intrusive porphyries; g, terrace gravel; d, Dakota sandstone.

When the geologic structure near Breckenridge is examined in detail the conception of regular monoclinal structure requires considerable modification. Minor folds and faults must be taken into account, but the chief disturbing element is the intrusion of the sediments and pre-Cambrian rocks by porphyries, which, though predominantly sheets or sills, nevertheless depart very widely from the regularity of form displayed by the intrusion of similar magma in the Tenmile district.

MOSQUITO FAULT.

The Mosquito fault, which limits the Breckenridge tectonic block on the west, lies 4 or 5 miles outside of the area here studied. As described by S. F. Emmons in the Tenmile folio, it is remarkably devious and varies in shade from place to place, so that along part of its course it is a normal dislocation and in another part it is a steep reverse fault. Emmons states that the initiation of the Mosquito fault, the uplift of the Mosquito or Tenmile Range, and the folding of the sediments in the Tenmile district occurred after the intrusion of the porphyries. Inasmuch as the Hayden map of Colorado indicates that in the Gore Mountains, north of the Tenmile area, the Dakota rests directly on the so-called Archean and transgresses westward over the line of the Mosquito fault, "passing without a break from a floor of Archean to one of Mesozoic sediments," Emmons was inclined to assign the fault a pre-Cretaceous, probably Jurassic age. He points out, however, that this supposition would make the porphyries older than similar porphyries elsewhere in Colorado and that final determination of the age of the Mosquito fault would better be postponed until further studies can be made, particularly of the relation of the fault to the Dakota in the Gore Mountains. It was hoped that there would be opportunity during the course of the Breckenridge work to visit these mountains and to gain some light on this question; but the season was fully occupied with problems more directly germane to the investigation in hand. It is clear, however, that the porphyries of the Breckenridge district are younger than the Upper Cretaceous shale and there can be little question that the similar porphyries of the Tenmile area are of the same age as those of Breckenridge. This part of the Hayden map, moreover, has proved to be so inaccurate that any detailed relations shown by it can have but little weight against opposing evidence. Finally, the Hayden map as it stands indicates a distribution of the Dakota in the Gore Mountains that is apparently not altogether incompatible with the view that the Mosquito fault cuts the Cretaceous beds. The continuation of the fault northward beyond the Tenmile-Breckenridge region, as Emmons truly remarks, invites much closer study. At present the evidence in favor of a late Cretaceous or Tertiary age for the Mosquito fault is preponderant.

EASTERN BOUNDARY OF THE BRECKENRIDGE TECTONIC BLOCK.

It has already been said that the Cretaceous beds of the Breckenridge area are faulted down against the pre-Cambrian on the east. The contact lies generally east of the area here studied in detail and has not been continuously traced. Apparently it is not due to a single fault but to a belt of complex faulting to which belong the poorly exposed irregular faults of various trends, which in the northeast corner of the mapped area (Pl. I, in pocket) separate the Upper Cretaceous shale, and apparently the porphyry also, from the pre-Cambrian. At Georgia Pass the mass of the shale is separated from the pre-Cambrian by the porphyry of Mount Guyot, which has some appearance of having been erupted partly along the fault zone. At the mouth of the Middle Swan there is a similar relationship between shale, quartz monzonite porphyry, and pre-Cambrian. Here, however, there is some shale between the porphyry and the pre-Cambrian gneiss, so that it is by no means clear that the fault fissure served as a channel for the porphyry magma. About a mile up the North Swan shale and porphyry are succeeded to the east by pre-Cambrian rocks, but the contact is not exposed. From this point the contact appears to run generally northwest to Snake River; but no satisfactory exposures of it were seen in the few places where it was crossed in reconnaissance. On the north side of the Snake, however, shale extends for about 7 miles above the mouth of the river, to a point about half a mile above the main forks. Here the shale is plainly faulted down against the pre-Cambrian gneiss, which rises as a cliff to the east of the soft sedimentary rock and marks an entire change of topography from the relatively low shale terrane with open stream valleys to bold ridges and deep ravines in the crystalline series.

Although at Georgia Pass the pre-Cambrian rocks, with a little disturbed and indurated quartzite and shale of doubtful age, are cut by hornblendic porphyry apparently belonging to the monzonitic series, it is not altogether clear that this hornblendic porphyry is an offshoot from the main mass of porphyry forming Mount Guyot nor that accordingly the faulting took place before or during the intrusion. Elsewhere, as in the vicinity of Muggins Gulch, such meager evidence as is available indicates that the porphyry, like the shale, is faulted against the pre-Cambrian and that consequently the faulting, in part, at least, was later than the main porphyry intrusions. This accords with Emmons's conclusions at Leadville and in the Tenmile district.

GENERAL STRUCTURE OF THE DISTRICT.

If the porphyry intrusions are for the present disregarded, the essential structural elements of the Breckenridge district are (1) the fundamental pre-Cambrian terrane as exposed along the flank of the Tenmile Range west of the Blue (see Pls. I, in pocket, and XII) and underlying the other formations in general; (2) the red "Wyoming" formation resting directly on the pre-Cambrian with a northeast dip of about 30° and from a thickness of perhaps 1,000 feet at the southern border of the district, thinning northwestward until it virtually disappears 3 miles north of Breckenridge; (3) the Dakota quartzite, 200 to 300 feet thick, stretching in a much broken and buckled band with prevailing low northeasterly dip from the middle of the south boundary of the mapped area to its northwest corner; (4) the Upper Cretaceous shale, over 3,000 feet thick, overlying the Datoka and dipping at angles ranging from 20 to 65° to the east or northeast; and, finally, (5) the pre-Cambrian, brought to the surface again by faulting.

The sediments have been intricately cut up and greatly disturbed or disrupted by the intrusion of the porphyries, chiefly in the form of very irregular sheets but also as dikes. In a rough way certain stratigraphic horizons of intrusion are recognizable. Thus, between the Dakota and the "Wyoming" are the quartz monzonite porphyry masses of Rocky Point, of the spur between Breckenridge and French Creek, and of the west slope of Gibson Hill. All these are of the intermediate variety. In the Dakota or in the lower part of the Upper Cretaceous shale are the thick and very irregular sheets of monzonite porphyry that make up most of Bald Mountain and Nigger, Prospect, and Mineral hills. Finally, throughout the shale formation intrusions of the silicic variety of quartz monzonite porphyry abound. While these generally show a tendency to follow the bedding of the shale their great irregularity of shape is evident from Plate I. It is safe to say that fully half the area studied is underlain by intrusive porphyry. The forcible injection of so much molten material into the sediments has greatly affected their structure. Beds originally contiguous have been forced apart and widely separated; others have been broken up and their fragments dispersed as inclusions through the magma; still others have been folded, crumpled, tilted, or faulted in the process of intrusion. The character of some of the intrusions is illustrated in miniature by figure 8, which is a sketch of a small sill intrusive in the partly shaly beds of the Dakota and exposed on the steep slope just northeast of Lincoln. The result of the porphyry intrusions is the production of a structure that can not be interpreted in detail. Even did the district afford satisfactorily full data regarding the surface relations of the rocks, as is far from being the case, deduction from these data of the actual underground structure would be impossible. The problem of determining the underground shape of such intrusive masses from a few surface observations may be likened to an attempt to ascertain the outlines of the porphyry areas north and south of the Swan on the basis of a few observations confined to the banks of that stream. These difficulties are dwelt on and emphasized in order that the reader should not credit the largely hypothetical sections presented in Plate XII with more detailed accuracy than they really possess. Their construction was an aid in forming a conception of the general structure of the district, and they may prove helpful and suggestive to the reader who remembers that they contain many inferences and are much generalized below the profile representing the surface.

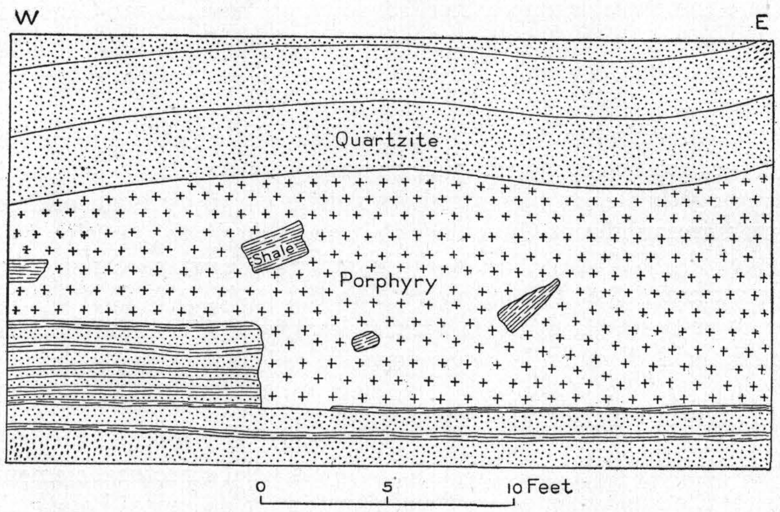
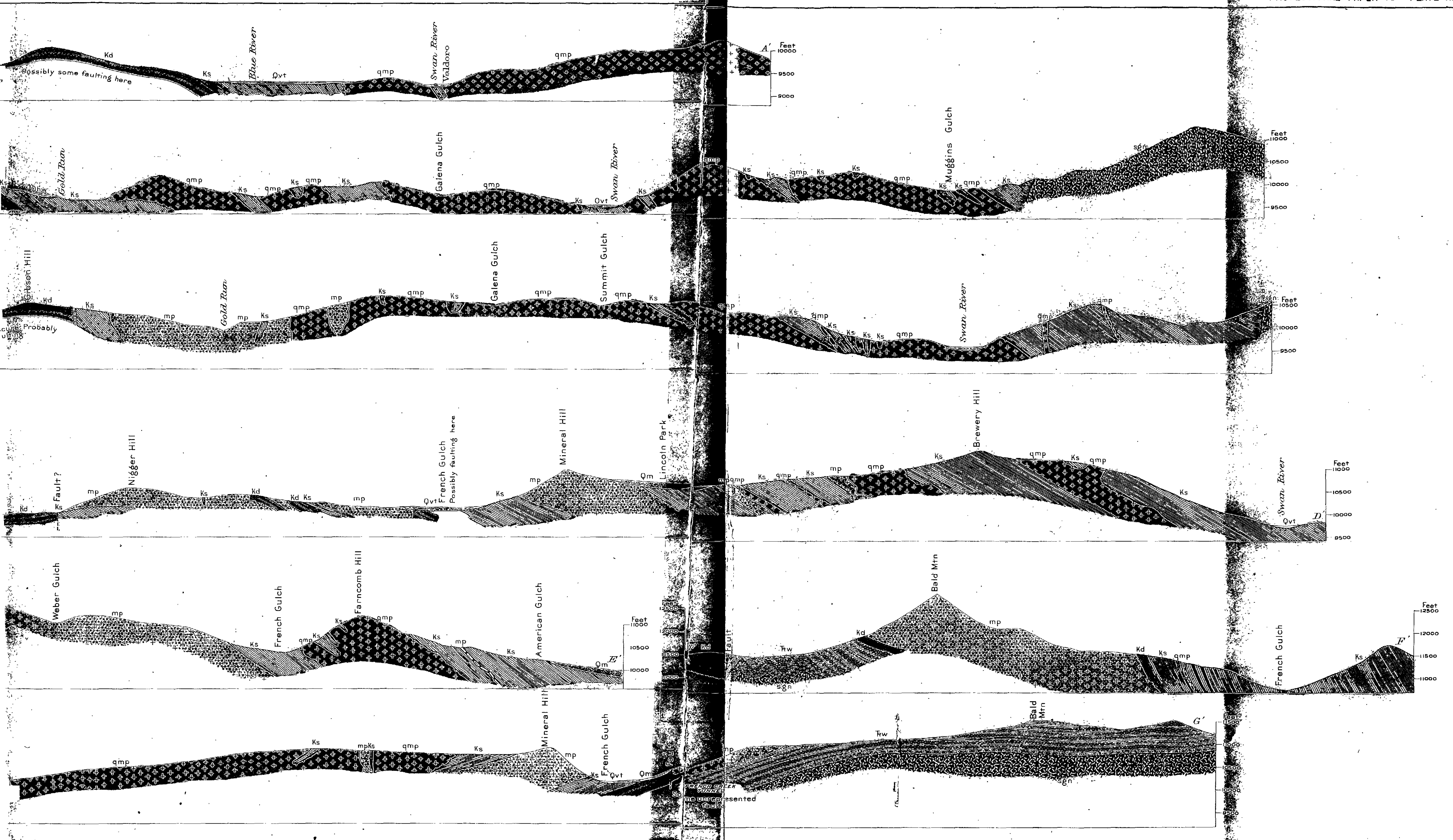


FIGURE 8.—Diagrammatic sketch of a small sill of quartz monzonite porphyry intrusive into shale and quartzite on slope northeast of Lincoln.

DAKOTA OVERLAP.

The disappearance of the pre-Dakota sediments along the east side of the Tenmile Range from Breckenridge northward is a feature so closely related to the structure of the district as to find appropriate consideration here. It may be remembered, from the descriptions in previous chapters, that beds ranging from the Cambrian to the Triassic, with a total thickness near Hoosier Pass that is probably somewhere between 5,000 and 10,000 feet, wholly disappear in a distance of about 10 miles northward along the Blue, so that the Dakota 2 miles north of Breckenridge rests on the pre-Cambrian. There is also a rapid thinning out of part of the same beds from west to east near the latitude of Breckenridge; for, according to Emmons, there are in the Tenmile district nearly 5,000 feet of pre-Dakota sediments, while near Breckenridge not over 700 feet of this series is represented, and 2 miles north of that town all has vanished. Emmons has suggested in the Tenmile folio that the Mosquito uplift took place in Jurassic time and that the absence of the "Wyoming" and older sediments along the lower Blue may be due to an unconformity thus produced at the base of the Dakota. It has been shown, however, on page 43, that the porphyries of the Tenmile district are probably Tertiary, or at least late Cretaceous, and if, as Emmons states, these porphyries are older than the Mosquito fault, then the uplift of the present Mosquito or Tenmile Range can not be the cause of the Dakota overlap. Moreover, if the deposition of the Dakota followed so sharp a local disturbance as the folding of the "Wyoming" and associated beds in the Tenmile area and the vigorous uplift of the range, then apparently there should be indubitable evidence of angular unconformity between the Dakota and the "Wyoming." So far as the work at Breckenridge shows, there is no such discordance, and the Dakota and Upper Cretaceous shale, as well as the older sediments, have been involved in the one great orogenic movement that has left a conspicuous mark on the region.



GEOLOGIC SECTIONS OF THE BRECKENRIDGE DISTRICT, COLORADO

By F. L. Ransome

Scale $\frac{1}{24000}$

1 Mile

1 Kilometer

1911

For explanation of formations see Plate I, in pocket

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

This movement accordingly took place in late Cretaceous or Tertiary time. Finally, it is to be remembered that the Dakota is not the only formation that overlaps the pre-Cambrian, although it does so more conspicuously than the older formations. At Hoosier Pass the Cambrian, Silurian, Devonian, and Carboniferous are all represented, while in Illinois Gulch near Breckenridge the "Wyoming" beds rest directly on the pre-Cambrian. Thus, even if it were possible to explain the Dakota overlap by the Mosquito uplift in Jurassic time, the "Wyoming" overlap and probably yet older overlaps below it would still remain to be accounted for.

As Emmons[1] has stated, the sites of the present Sawatch and Colorado or Front ranges were probably occupied by land areas throughout the Paleozoic era. The pre-Cretaceous beds contain much coarse material and were evidently derived from no very distant masses of disintegrating pre-Cambrian rocks. In many places they are clearly littoral deposits. It appears probable that the progressive overlap of the Paleozoic formations, culminating in the wide sweep of the Dakota, is the record of a gradual though probably not uniform transgression of the sea over the pre-Cambrian land areas. A large region north of Breckenridge and east of the present crest of the Tenmile Range, embracing the crest of the Front Range, was probably never covered by the Paleozoic sea and was submerged only when the Dakota mantled its worn surface. From Breckenridge south to Hoosier Pass a slope ranging from 1 in 10, or about 5°, to 1 in 5, or about 10°, would have permitted the accumulation of 5,000 to 10,000 feet of sediments at the site of the pass before the advancing sea began to deposit material where Breckenridge now stands. A similar gradient to the west, of 10° or less, would account for the difference in sedimentation in the Breckenridge and Tenmile districts. The comparatively steep offshore slope in this direction, resulting in the heavy accumulation of sediments just west of the present Tenmile Range, may have been an important factor in the initiation of the Mosquito fault and the uplift of the mountain ridge.

It is not supposed that the sea encroached steadily upon the land throughout Paleozoic and early Mesozoic time. There were probably many oscillations and it is known that elsewhere in Colorado (see p. 30) distinct unconformities intervene between the Permian and Triassic beds and between the Maroon and Gunnison formations. It is quite possible that the movements which produced these unconformities affected the Breckenridge region also. Their influence, however, has not been definitely recognized.

One economically important consequence of the overlap is the absence from the Breckenridge district of the ore-bearing limestones of Leadville.

STRUCTURAL DETAILS.

Plan of description.—The rough outline of the structure already presented requires filling in before it can be accepted as a reasonably satisfactory picture of the whole. This perhaps may be most clearly and systematically accomplished by taking up in order the sections shown in Plate XII (p. 66) and commenting on the structural relations existing in the vicinity of each.

Section A–A′.—In section A–A′ the pre-Cambrian basement as exposed in North Barton Gulch appears on the left. Upon this rests the Dakota, which covers a considerable area northwest of Braddocks. The "Wyoming" here is lacking or is represented merely by a few reddish pebbly beds and a little dark-red shale not clearly separable, according to Mr. Bastin, from the basal part of the Dakota.

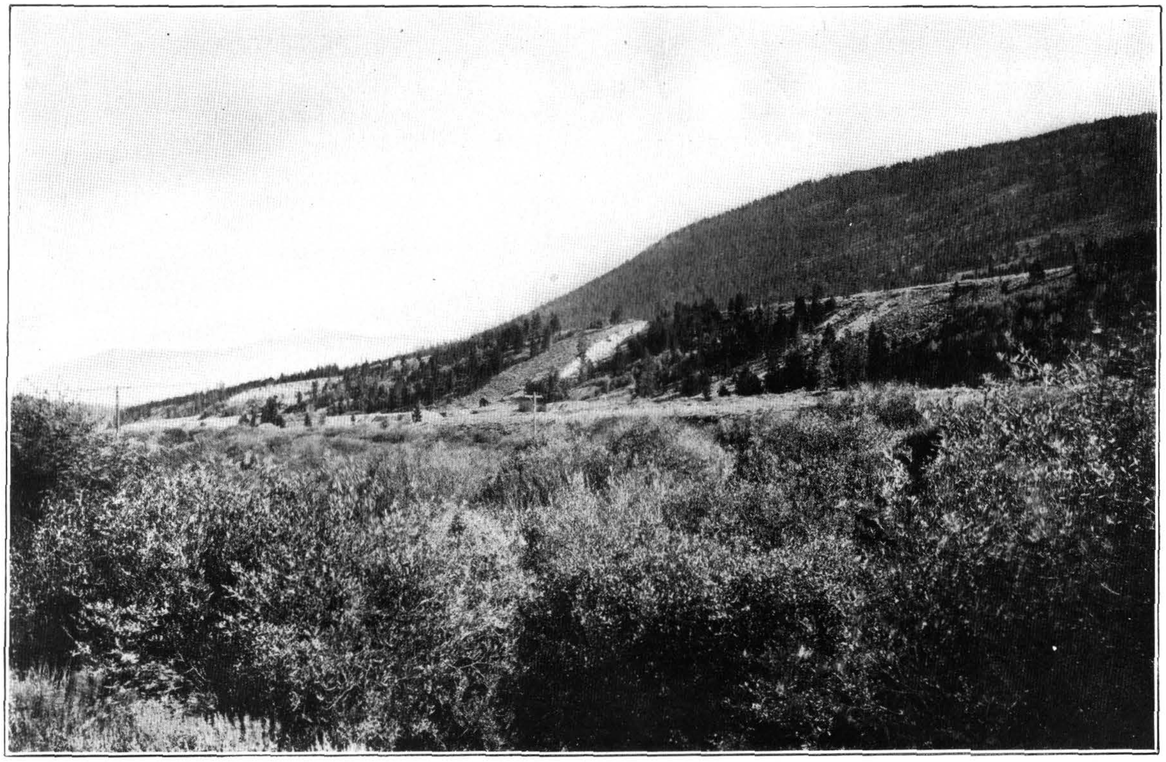
The structure of the quartzite, owing to poor exposures and the thickness of the beds, is obscure and there is no place where its thickness is measurable. The beds are probably gently folded and perhaps faulted. The structure shown in the section is generalized and largely hypothetical. Overlying the quartzite with a dip of 30° to 40° is Upper Cretaceous shale, which here forms most of the bedrock beneath the auriferous gravel in the valley of the Blue. Between the Blue and the Swan is a low hill carved from an irregular intrusive mass of quartz

[1] Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 21–30.

monzonite porphyry, then another narrower belt of shale in the bed of the Swan, succeeded by the very large body of quartz monzonite porphyry northeast of Valdoro. In the main this is probably a thick irregular intrusive sheet which is known to include many disrupted fragments and masses of shale. There is nothing to show, however, that the porphyry does not in some places continue downward across the stratification to its magmatic source.

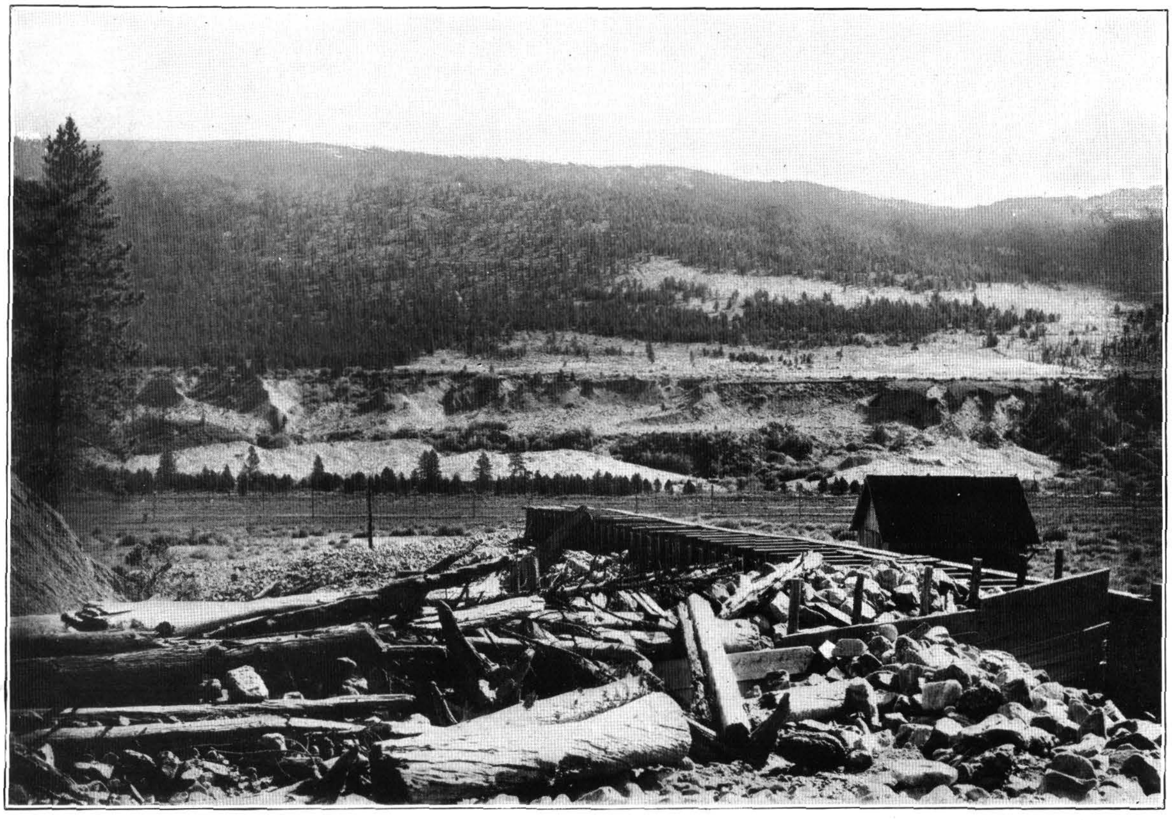
Section B–B′.—Section B–B′ shows on the west of the Blue the terrace gravels between Barton and Cucumber gulches resting on the pre-Cambrian. It is possible, however, that some of the Dakota quartzite of Cucumber Gulch (see Plate I, in pocket) may extend as far north as the line of the section. Here the channel of the Blue is excavated in the pre-Cambrian, as shown by exposures along its banks and by drill holes. East of the Blue the "Wyoming" formation is represented by some beds of conglomerate succeeded by red sandstone and shale. The basal beds are exposed in the bottoms of some of the old hydraulic workings along this side of the Blue, but the upper beds are concealed by terrace gravel and soil. The thickness of the "Wyoming" on the line of section B–B′, provided no faulting has affected it, is from 500 to 700 feet. This is rather remarkable in view of the virtual absence of the formation in the vicinity of the Barton gulches and suggests some concealed faulting. Overlying the "Wyoming" beds is a great intrusive mass of porphyry which on the supposition that it has the general shape of a sill is fully 1,300 feet thick. It terminates abruptly at both ends. At the north some intrusive contacts are exposed, the porphyry cutting quartzite, calcareous gray shale, and reddish shale without perceptible metamorphism. At the south the relations of the porphyry to the pre-Cambrian and Dakota are very obscure. Numerous prospect pits in this vicinity show a peculiar decomposed breccia consisting chiefly of porphyry fragments and partly rounded bowlders but including also some blocks of pre-Cambrian material. The large fragments are held in a light-gray matrix which appears to consist mainly of triturated porphyry and has the general aspect of a tuff. The origin of this material is a puzzling problem. It appears to underlie the soil and surface detritus over an area of nearly a quarter of a square mile and can hardly be a fault breccia. There is no evidence elsewhere in the district of local explosive volcanic activity. The most plausible explanation appears to be that the south end of the porphyry mass was intruded in an extremely viscous condition and was brecciated and triturated by the motion of its own intrusion. This is not altogether a satisfactory suggestion, but in the absence of good exposures of the material it is all that can be offered. The breccia is mapped as quartz monzonite porphyry on Plate I and occupies that part of the porphyry area lying south of the more northerly of the two roads shown crossing the western slope of Gibson Hill.

Overlying the porphyry and forming the crest of the north spur of Gibson Hill is the Dakota quartzite, which strikes from north to north-northwest and dips east at angles ranging from 30° to 40°. Unless there is some faulting or concealed folding this dip requires a much greater thickness in the Dakota than is probably attained by that formation. Consequently as a suggestion of what may be the actual structure two hypothetical faults are introduced in the section. The quartzite is followed in normal sequence to the northeast by a thick belt of Upper Cretaceous shale, which is the prevailing bedrock of the Gold Run placers. As is often the case, the natural exposures of this relatively soft rock are exceedingly unsatisfactory, and in mapping much dependence must be placed on prospect pits and placer workings. On the northeast side of Gold Run the black shale, as shown by the workings of the Jessie mine, extends in part under the same very irregular mass of porphyry that forms the hills east of Valdoro. Between Gold Run and the pre-Cambrian area in the northeast corner of the district the section crosses many alternations of porphyry and shale. Some of the shale masses are indubitably inclusions wholly surrounded by the igneous rock; others perhaps are connected with the main body of the shale. Finally, at the northeast end of the section shale and porphyry are shown faulted down against the pre-Cambrian. The fault plane is nowhere exposed, but dislocation is inferred from the fact that the shale maintains its northeasterly dip close up to the pre-Cambrian rocks. The Dakota, moreover is absent, and the shale in this part of the district is stratigraphically some thousands of feet at least above the base of the Cretaceous.



A. VIEW NORTH DOWN THE VALLEY OF THE BLUE FROM A POINT NEAR THE MOUTH OF FRENCH GULCH.

The camera was set on the surface of the valley train. The willows in the foreground are growing on recent alluvium in the trench of the present stream. Beyond them is the valley-train terrace, approximately on a level with the camera, and behind that is the older bench formed by the terrace gravels. See page 72.



B. TERRACE GRAVELS ON THE EAST SIDE OF THE BLUE ABOUT A MILE NORTH OF BRECKENRIDGE.

The view is from the Banner placer on the west. The terrace is the same as that seen in *A*. The wooded hill in the background is the north spur from Gibson Hill and is porphyry capped with quartzite. See page 72.

Section C–C′.—Section C–C′ shows at its southwest end some morainal material and terrace gravel resting on rock which is nowhere exposed near by but which is probably in part pre-Cambrian. Near Shock Hill is some Upper Cretaceous shale, with an unusual local dip to the west, overlain and perhaps irregularly cut by monzonite porphyry. The structure at Shock Hill is apparently a shallow syncline opening to the south. The Dakota is probably the bedrock of the Blue along this section and continues over to French Creek. There is no suggestion of close folding and the beds are probably gently flexed, as indicated in the section. Whether or not they are also faulted is unknown. There is a little purplish-red shale on the northeast side of Shock Hill which is interbedded with the normal Dakota quartzite.

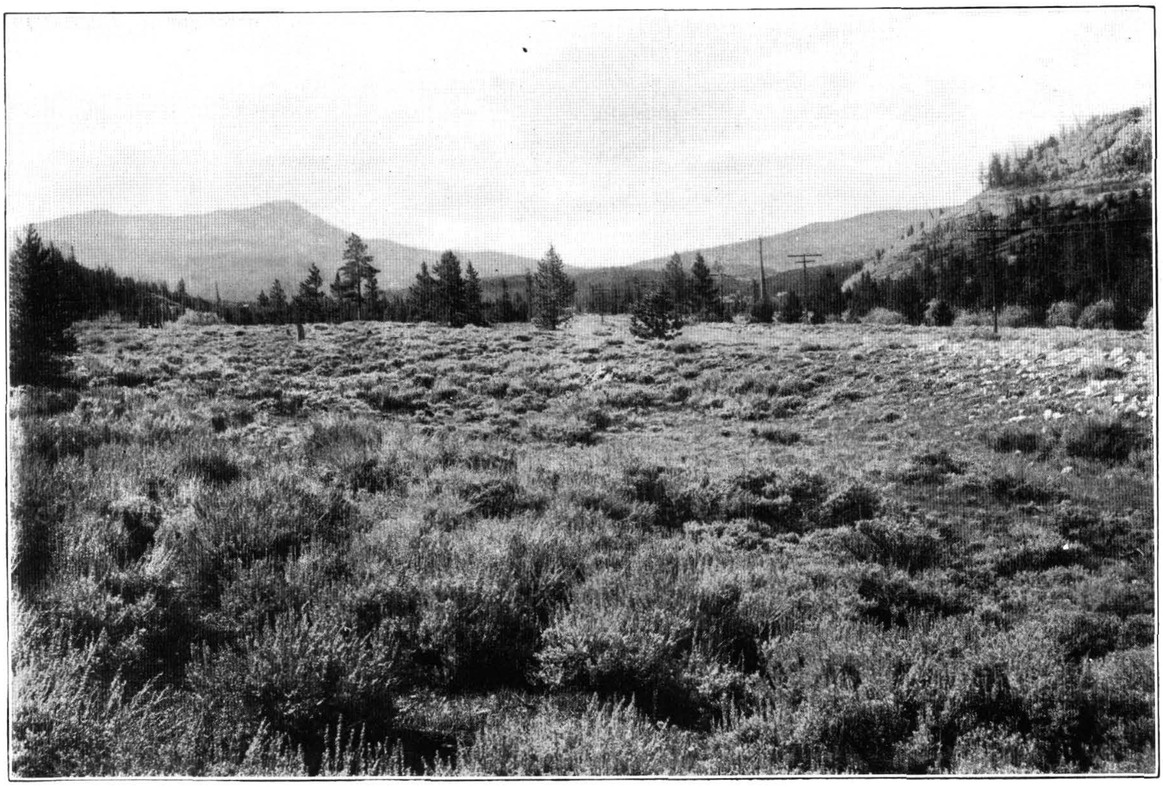
On the northeast side of French Gulch the pre-Cambrian makes its appearance, and it is necessary to conclude that the Dakota is brought against the older terrane by a fault concealed by the gravels of French Gulch. The same or another fault is necessary also to account for the relation between the "Wyoming" formation and the pre-Cambrian on the west slope of Gibson Hill, just north of the line of the section. At the base of the hill "Wyoming" beds with a dip to the east rest on the pre-Cambrian, but, as shown on Plate I (in pocket), the pre-Cambrian reappears much higher up the slope. The position and trend of this fault can not be ascertained on account of the extensive cloaking of this part of the district by gravels. As the section is followed up the slope of Gibson Hill the pre-Cambrian is succeeded by the Dakota. The exposures here are exceedingly poor, but the course of the contact, the absence of recognizable "Wyoming" beds, and the fact that the quartzite and associated shale dip toward the pre-Cambrian in the one or two places where observations could be made, all indicate that the pre-Cambrian is bounded on this side also by a fault, as suggested in the section. The structure of the quartzite on Gibson Hill is obscure. Numerous tunnels and shafts enter the hill, but no work was in progress in any of them during 1909 and they are generally inaccessible. The dumps of some show considerable red shaly material, similar to that on Shock Hill, which apparently is interbedded with the quartzite. The structure as represented in the section rests upon a very slender basis of fact. On the east end the quartzite is separated from the Upper Cretaceous shale by a dike of quartz monzonite porphyry that apparently occupies a fissure along which some faulting has taken place, the shale having been dropped against the quartzite for a distance of 200 or 300 feet. East of the shale lies a great mass of monzonite porphyry, which is the principal rock of Prospect and Mineral hills and was probably once continuous with the porphyry of Nigger Hill and Bald Mountain. The sheetlike character of the intrusion is here scarcely recognizable, and the monzonite porphyry, as may be seen from Plate I, cuts the sedimentary rocks most irregularly in the vicinity of Gibson and Prospect gulches. This porphyry, which includes some masses of shale, continues across Gold Run and is then succeeded by the quartz monzonite porphyry of the great irregular sheet with dike apophyses already described in connection with sections A–A′ and B–B′. Exposures throw no direct light on the character of the contact between the two porphyries. From evidence presented on page 71 it is supposed that the quartz monzonite porphyry cuts the monzonite porphyry, and this relation is indicated in the section by a conventional jagged line. Northeast of this contact the section cosses a small mass of monzonite porphyry thought to be an inclusion in the more siliceous eruptive. After passing through many masses of shale, probably for the most part ragged inclusions caught up in the magma, the plane of the section crosses the Swan, goes through a thick division of the Upper Cretaceous shale, and ends in the pre-Cambrian, against which the shale is faulted, as described in connection with section B–B′.

Section D–D′.—Section D–D′ shows on the left the morainal deposits south of Breckenridge resting in part on the pre-Cambrian. Somewhere in the space left blank in the section west of the Blue there is probably a considerable thickness of the red "Wyoming" beds, but nothing is positively known concerning the character of the bedrock beneath this part of the moraine. East of the Blue the section crosses the quartzite, shale, and porphyry of the vicinity of the Puzzle mine and Little Mountain. The structure here is more complex than can be shown in the section. The monzonite porphyry cuts the quartzite irregularly and has also forced its way as sheets between the beds, as may be seen in the Puzzle-Gold Dust mine. Between the quartzite and shale along Dry Gulch there is apparently a fault whose fissure is occupied by the Gold Dust vein. On the north side of Illinois Gulch a lessees' tunnel on the Dunkin ground goes through about 200 feet of monzonite porphyry and then passes into black shale, in which it continues for several hundred feet to the face, as it was in 1909, although all the upper workings on the Dunkin group of claims on Nigger Hill are in the porphyry. The same shale with some beds of compact gray limestone underlies the porphyry at the middle railway bridge over Illinois Gulch. Here the base of the porphyry conforms to the bedding of the shale and dips to the north at about 35°. It appears that the porphyry of Nigger Hill is a thick uneven sheet resting in part on shale. In some places the lower surface conforms to the bedding, in others it cuts across the beds at various angles, and in still others it may continue down through the shale to great depth. In the section an attempt is made to generalize these relations. The chances are that most shafts on Nigger Hill, if sunk deep enough, would go through the porphyry into quartzite or shale. The various masses of shale and quartzite crossed by the section between Nigger Hill and French Gulch are possibly inclusions in the porphyry; but the structural relations seen in the Country Boy and Helen tunnels indicate that the larger bodies are probably continuous with the main mass of sediments underlying the greater part of the porphyry. The tunnels mentioned reveal far greater complexity than can be shown in a section of this scale. It is evident that the lower part of the porphyry splits into a number of sills and that faulting has greatly complicated the structural details. Under the gravels of French Creek, where crossed by the section, are Dakota quartzite and Upper Cretaceous shale, some of the black shale appearing on the north side of the creek at the base of Mineral Hill. The main mass of Mineral Hill is monzonite porphyry, which apparently is an irregular sill about 1,200 feet thick at this place. The areal relations indicate that it is a part of the same sill that forms Bald Mountain. If so, it has been uplifted relatively to the Bald Mountain mass by faults along French Creek. Northeast of Lincoln Park the underground relations between the porphyries and shale, as indicated in the section, are almost wholly hypothetical.

Section E–E′.—On the left section E–E′ begins in morainal material, which probably covers "Wyoming" beds. Above these is a thick sheet of quartz monzonite porphyry of the intermediate variety, which has been intruded between the "Wyoming" and the Dakota. The bedding of the Dakota is not shown at this point. It was presumably much disturbed by the force of the intrusion. Northeast of this is considerably disturbed Upper Cretaceous shale, cut by a mass of monzonite porphyry that apparently is too irregular to be a sill. Northeast of this in turn is Dakota quartzite resting on "Wyoming" beds and separated from a part of the same formation by a fault that is nowhere actually exposed, although the general character of the contact leaves little doubt of its presence. Between the fault and Bald Mountain the section crosses a small irregular dome or quaquaversal, which results in the exposure of a small area of pre-Cambrian in the upper part of Illinois Gulch. (See Pl. I, in pocket.) On the east side of this pre-Cambrian the gently dipping beds of the "Wyoming" formation have a thickness of about 1,000 feet and are overlain by some of the basal beds of the Dakota, covered in turn by the great monzonite porphyry sill of Bald Mountain. This sill appears to have been intruded along the bedding planes of the Dakota, and, as shown on Plate I, fragmentary masses of strata referable to that formation occur as inclusions in the sill or rest upon its upper surface at several places overlooking French Gulch. Crossing the Upper Cretaceous shale belt of French Gulch the section passes through the intrusive quartz monzonite porphyry mass of Farncomb Hill. This is a highly irregular body which has sent out both dikes and sills into the surrounding shales.

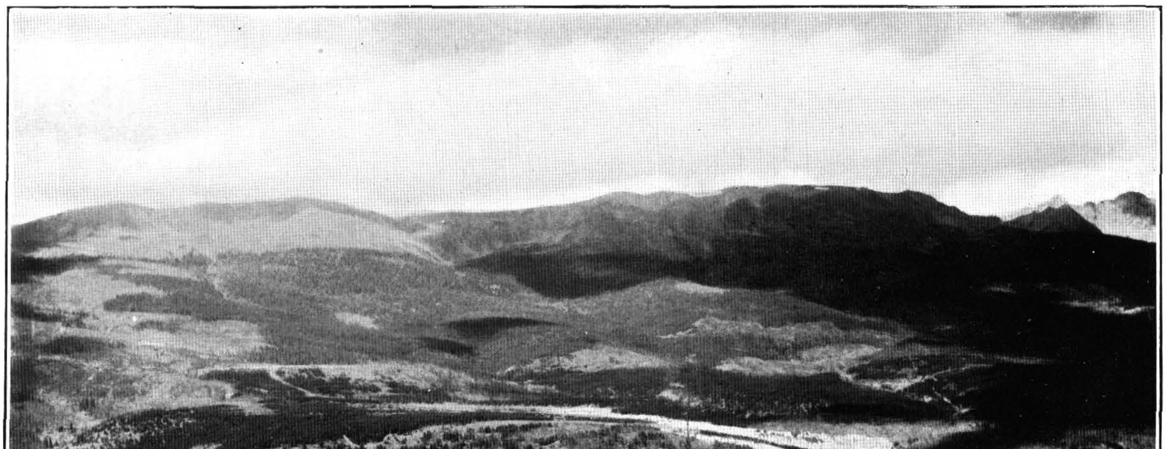
Section F–F′.—Section F–F′ also crosses part of the quaquaversal uplift. The folds shown in the "Wyoming" are an attempt to generalize from the data of a few poor exposures. The depth and form of the pre-Cambrian surface are conjectural.

Section G–G′.—Section G–G′, which differs from the others in being nearly meridional, is of interest as showing the extent of the great Swan River mass of quartz monzonite porphyry and



A. VIEW SOUTH UP THE VALLEY OF THE BLUE FROM THE ROADSIDE THREE-QUARTERS OF A MILE NORTH OF BRECKENRIDGE.

In the foreground is the nearly level bowlder-strewn surface of the valley train. On the right is Shock Hill. The distant peak is Red Mountain, east of Hoosier Pass. See page 79.



B. TERRACE GRAVELS WITH BANNER HYDRAULIC WORKINGS ON THE WEST SIDE OF THE BLUE.

The view is from Gibson Hill near the abandoned Kellogg mine. In the distance is the Tenmile Range To the left of the placer is Cucumber Gulch. The tunnels just to the left of the mouth of Cucumber Gulch belong to the Iron Mask mine. See page 79.

the relation of the monzonite porphyry bodies of Mineral Hill and Bald Mountain. The French Creek tunnel, indicated on this section, shows clearly that the sedimentary beds, at this place at least, virtually pass entirely under the monzonite porphyry. The structure visible in this tunnel can not all be shown on the scale of Plate XII (p. 66). A more detailed section is given in figure 15, on page 138. The lowest beds, exposed at the face of the tunnel, are gray, micaceous, arkosic grits with disseminated pyrite. These sandstones, partly pebbly and unquestionably belonging to the "Wyoming" formation, although they are not red, are overlain by reddish shale identical with that cut in the Gold Bell tunnel on Bald Mountain. This shale probably belongs at the top of the "Wyoming," although it is possibly in the Morrison formation. A little quartzite, supposedly Dakota, occurs near the portal of the tunnel.

RELATIVE AGES OF THE PORPHYRIES.

The question whether the monzonite porphyry cuts the quartz monzonite porphyry, or vice versa, is one not easily answered. The two rocks, so far as exposures in this district are concerned, do not grade into each other, although there are varieties intermediate between the two extreme types. Where one porphyry comes against the other, the contact as a rule is as definite as between other rocks distinguished in mapping. Nowhere in the district, however, so far as known, is there a place where the actual contact between fresh rocks of both kinds is exposed. On Prospect and Mineral hills and in the workings of the Wellington mine the quartz monzonite porphyry appears to cut the monzonite porphyry, or diorite porphyry, as dikes. On the other hand, as Plate I shows, there are a few masses of the more femic variety inclosed in the quartz monzonite porphyry. Are these small intrusive bodies or are they inclusions? There appears to be no practicable way of determining. Many of them are accompanied by shale, and the probability is that, like the shale, they are inclusions caught up in the more silicic rock. On the whole, while the porphyries were probably erupted close together in time, it is believed that the monzonite porphyry is older than the quartz monzonite porphyry.

CHAPTER V.

QUATERNARY DEPOSITS.

INTRODUCTORY STATEMENT.

The Quaternary deposits in the Breckenridge district may in part be divided into glacial accumulations of Pleistocene age and stream gravels of the Recent epoch. During the Pleistocene there were two distinct cycles of advance and retreat and each has left a depositional record. The earlier is represented by what may conveniently be designated terrace gravels and possibly by what will be called the older hillside wash; the later by moraines and low-level gravels. These various deposits will be described in the general order of age.

TERRACE GRAVELS.

DISTRIBUTION.

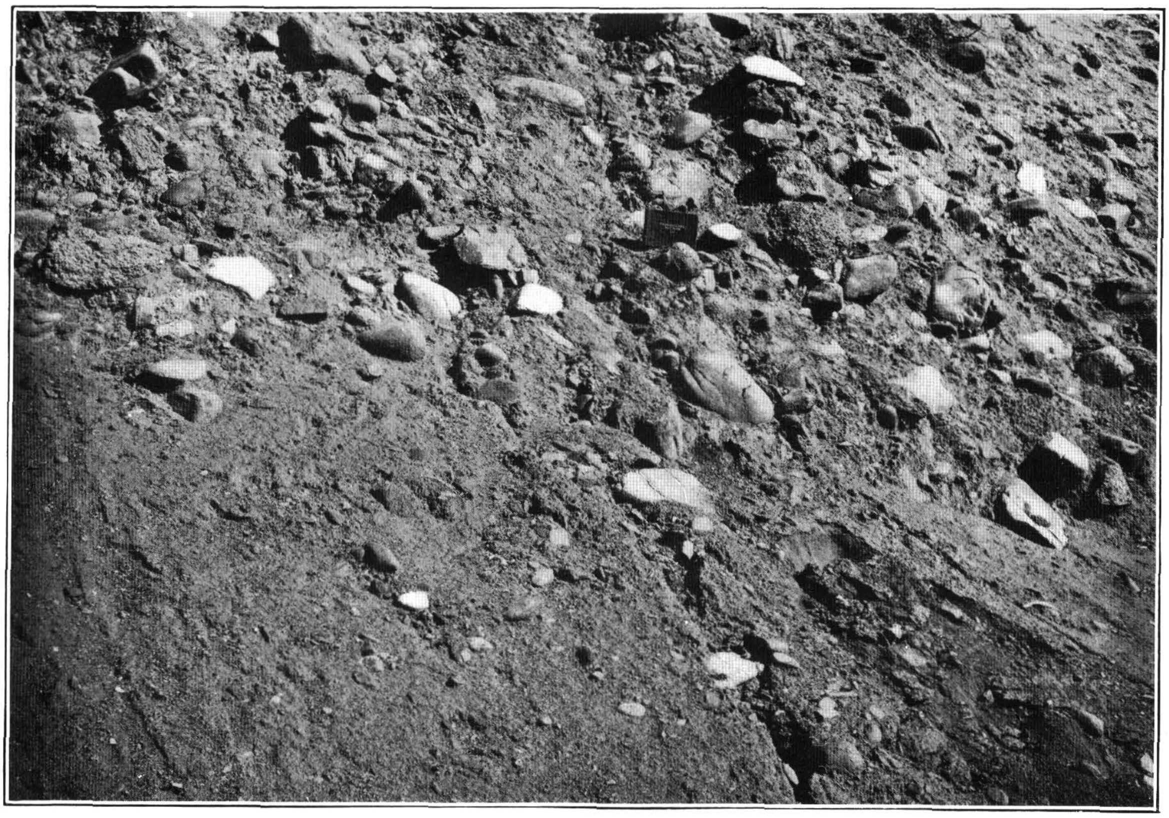
The terrace gravels occur along both sides of the valley of the Blue from a point about a mile south of Breckenridge northward to Dickey, a distance of 7¼ miles, and perhaps beyond Dillon, some gravel being reported on the west side of the Blue 15 miles north of Breckenridge. Their principal development, however, is within the boundaries of the district, where, as shown in Plate XIII, their terrace character is more evident in the landscape than on a map with so large a contour interval as 50 feet. At the latitude of Breckenridge the old fluvial gravel plain, of which the terrace deposits are remnants, must have had a width of 2½ miles. It was probably wide also in the vicinity of Braddocks and may have extended over the area now known as Delaware Flats up the Swan as far as Galena Gulch. North of the junction of the Blue and the Swan, however, the valley narrows, and although it opens again toward Dickey the constriction appears to be the northern limit of the important areas of terrace gravel. The greatest height to which the gravel extends is not easily determined, as the material generally merges with the local wash from the slopes back of the terrace. Southwest and west of Breckenridge the terrace gravel appears to attain an elevation of 10,250 feet, or 650 feet above the Blue. On the spur east of Breckenridge over which passes the road to French Gulch the gravel reaches an elevation of at least 10,000 feet, or 250 feet above the nearest point on French Creek. On the spur south of Braddocks the upper limit of the gravel is at about 9,600 feet and northwest of Valdoro at 9,400 feet, or 250 feet above the point where the Blue and Swan unite.

THICKNESS.

The base of the terrace deposits is probably everywhere above the channels of the streams that now dissect them, although in many places no rock is exposed between the terrace gravels and the low-level gravels. The important sheet of terrace gravel east of Breckenridge, for example, merges with the low-level gravel along the Blue and along French Creek, except at the northwest end of the spur, where the higher gravel rests on quartzite about 50 feet above the present streams. Along the east side of the Blue, from French Gulch to Braddocks, the base of the terrace gravels is in most places at about the same height above the present flat floor of the valley. On the west side of the river there is less regularity in the altitude of the base of the gravels, and it is clear that here the surface upon which they were deposited was uneven. The old valley was broad and was diversified by low hills and spurs against whose slopes the gravels accumulated, in some places to the extent of complete burial. Shock Hill, for example, at one stage of valley aggradation must have stood out as a rocky island in a gravelly plain. Under these circumstances the maximum or average thickness of the gravel is

A. TERRACE GRAVELS OF THE BANNER PLACER, 1 MILE NORTH OF BRECKENRIDGE.

Rounded gravels in the lower layers (partly covered by loose detritus). Above these are some sandy layers and then coarse subangular material. See page 73.



B. NEARER VIEW OF THE BASAL DIVISION OF TERRACE GRAVELS ILLUSTRATED IN *A*, SHOWING THE ROUNDNESS AND DECOMPOSITION OF THE BOWLDERS.

The notebook is 8 inches long. A characteristic crumbling granitic bowlder is about a foot to the right of the book. See page 73.

not easily estimated. Along the west base of Gibson Hill the deposits are probably nowhere over 50 feet thick, and they thin out on a rising floor to the east. Between Breckenridge and French Creek the terrace gravels have been extensively worked by the hydraulic method and the old pits show thicknesses ranging from 10 to 20 feet, so that these gravels constitute a comparatively thin layer over slopes very similar to those of the present surface. Due west of Breckenridge the old hydraulic workings south of Shock Hill show a maximum thickness of about 50 feet. Between Shock Hill and Barton Gulch, in the Banner hydraulic workings (see Pls. XIV and XV), the banks of gravel are from 75 to 100 feet high, this being probably the thickest deposit of terrace gravel exposed in the district, although it is by no means certain that shafts or borings would not reveal greater thicknesses in some of the large masses west of the Blue. It is reported that a hole 250 feet deep was drilled in the terrace gravel west of Breckenridge without reaching solid rock. The exact position of this hole was not ascertained, however, and it possibly went through some morainal material as well as terrace gravel.

CHARACTER OF MATERIAL.

The bowlders in the typical terrace gravel are well rounded and range up to 4 feet in diameter, although those over 2 feet are uncommon. They consist of various granitic and schistose rocks derived from the pre-Cambrian at the head of the Blue or brought down by lateral tributaries from the near-by slopes of the Tenmile Range. With these are mingled red and gray micaceous sandstones from the "Weber," Maroon, and "Wyoming" formations exposed south of Breckenridge; quartzite, probably in part from the "Sawatch" quartzite at the head of the Blue but mainly from the Dakota; and, finally, porphyries of the various kinds found in the district. In the excellent exposures in the Banner hydraulic workings (see Pl. XV) the lower 15 to 20 feet of the deposit, resting on the pre-Cambrian, consists of well-rounded, rather large cobblestones embedded in fine gravel and sand. The bowlders at this place are mostly of pre-Cambrian rocks, but some are quartzite. As a rule nearly all the rounded bowlders in the terrace gravels except those of quartzite are more or less decomposed, and those of granite, gneiss, or red sandstone are generally so soft that they can readily be picked to pieces. The disintegrated state of some of them is apparent in Plate XV, *B*.

Above this bed of bowlders in the Banner placer is a 6-foot layer of stratified sand and clay with some scattered pebbles (Pl. XV, *A*), grading upward into rather angular gravels, which, although consisting of very imperfectly assorted material, show rude, indistinct stratification. Irregularly distributed through the finer gravelly and clayey matrix of these upper beds are some rather angular masses of quartzite up to 5 feet in length, with smaller and more rounded bowlders of pre-Cambrian rocks, which are generally decomposed.

On the opposite side of the Blue (see Pl. XIII, p. 68), the terrace gravels as exposed in the pits between the 2-mile bridge and French Gulch contain large well-rounded bowlders of pre-Cambrian rocks and of red sandstone, many of which are decomposed.

Pre-Cambrian material is abundant in the western part of the gravel mass east of Breckenridge, but in the placer pits, which are mostly on the French Creek slope of the spur, pre-Cambrian bowlders are rare while those of quartzite and porphyry are very common. Many of the porphyry bowlders, however, are so soft that they go to pieces under the impact of the water from the monitors or crumble later on exposure. The bowlders are rudely stratified with yellow sandy clay and occur mostly near the bottom of the deposit.

The terrace gravel of the broad, low spur south of Braddocks, between Gold Run and the Blue, is composed of well-rounded material consisting largely of detritus from the pre-Cambrian terrane. On the Gold Run side of the spur this material appears to grade into the more angular hillside wash presently to be described.

On the south side of the Swan, between Delaware Flats and Galena Gulch, one hydraulic pit exposes well-rounded terrace gravel resting on bedrock about 250 feet above the floor of Swan Valley. The bowlders are mostly of crystalline rock and have probably come from the pre-Cambrian near the heads of Muggins Gulch and of the main forks of the Swan. They are up to 2 feet in diameter and are generally decayed. This gravel is only about 5 feet thick at this place and is overlain by about 25 feet of hillside wash.

The matrix in which the bowlders of the terrace gravel are held varies from coarse gravel to fine clay. Generally it is a sandy or clayey gravel in which are pebbles and cobblestones of all sizes up to those of the largest bowlders. The gravels as a rule are cemented by nothing harder than clay and as this is not of a particularly tough variety they can be readily broken down by the impact of water under moderate pressure.

CORRELATION WITH DEPOSITS OUTSIDE OF THE DISTRICT.

East of the Rocky Mountains no less than six distinct advances of the ice during the Pleistocene have been recognized. In the middle Cordilleran region, on the other hand, the most careful recent study has failed to reveal more than two epochs of maximum glaciation. Possibly there were others, but as Atwood[1] has observed, there are peculiar difficulties in the way of distinguishing separate ice advances in a mountainous region owing to the readiness with which a late canyon glacier may obliterate the traces of an older one.

In the Leadville district, recently studied by S. R. Capps,[2] the deposits left by the first epoch are represented by remnants of moraines and by the accumulation of terrace gravels in the valley of the Arkansas. Hayden[3] appears to have been the first to describe these gravels. He regarded them as having been laid down in a lake at the close of the glacial epoch. Later, S. F. Emmons[4] also described them as "glacial or lake" beds and noted that they range from fine calcareous marls to coarse bowldery gravels. A fluvio-glacial origin for the terrace gravels near Leadville was urged by Capps and Leffingwell[5] in 1904 and by Westgate[6] in 1905; but Emmons and Irving[7] later stated that the terrace deposits are divisible into two parts—a lower one consisting of fine-grained stratified arkosic sands with some clay and an upper one of coarse gravels. These writers believe that the finer material is probably lacustrine and that only the overlying gravel or "wash" is of glacio-fluviatile origin. Finally, in 1909, Capps[8] laid stress on the very close relation between the terrace deposits and the older drift and maintained that the terrace deposits have no lacustral characteristics but were deposited by overloaded extra-glacial streams fed by the melting of the older glaciers. He noted that a large proportion of the bowlders in the terrace gravels are decomposed.

There can be little question that the terrace gravels of the Leadville area and those in the valley of the Blue were laid down contemporaneously. The latter clearly represent the work of aggrading streams.[9]

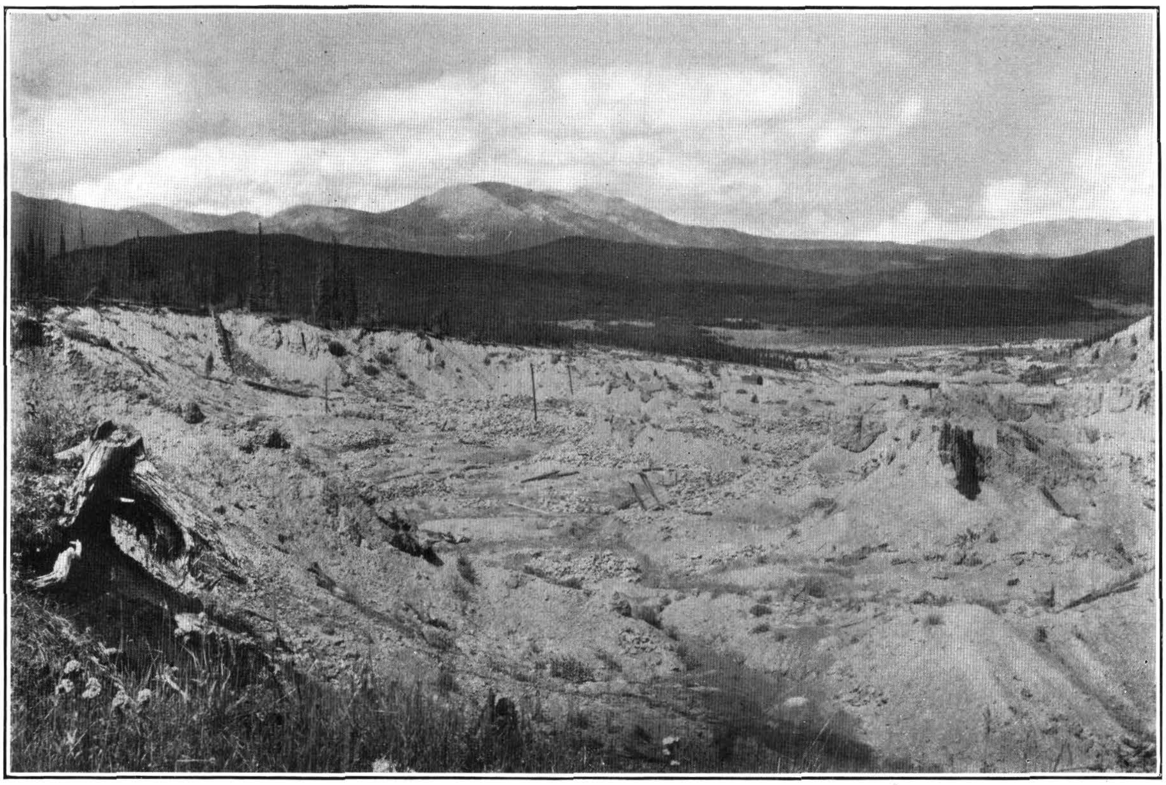
Two glacial epochs were recognized by Ball[10] in the Georgetown quadrangle and the remnants of older till described by him probably accumulated while the terrace gravels were being deposited near Breckenridge. No real morainic material belonging to the older epoch has been found in the Breckenridge district.

OLDER HILLSIDE WASH.

DEFINITION.

Hillside wash is a rather comprehensive term that may include deposits of widely different age and volume. Along Gold Run many of the gulches in the Breckenridge district, particularly those on the north slope of Farncomb Hill, are accumulations of soil and angular rock

[1] Atwood, W. W., Glaciation of the Uinta and Wasatch Mountains: Prof. Paper U. S. Geol. Survey No. 61, 1909, p. 68.
[2] Pleistocene geology of the Leadville quadrangle, Colorado: Bull. U. S. Geol. Survey No. 386, 1909.
[3] Hayden, F. V., Rept. U. S. Geog. and Geol. Survey Terr. for 1873, 1874, pp. 52–53.
[4] Geology and mining industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 71.
[5] Capps, S. R., and Leffingwell, E. D. K., Pleistocene geology of the Sawatch Range: Jour. Geology, vol. 12, 1904, pp. 702–704.
[6] Westgate, L. G., The Twin Lakes glaciated area, Colorado: Jour. Geology, vol. 13, 1895, p. 295.
[7] Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: Bull. U. S. Geol. Survey No. 320, 1907, pp. 10–18.
[8] Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colorado: Bull. U. S. Geol. Survey No. 386, 1909, pp. 17–20.
[9] Capps mapped as "drift of older epoch of glaciation" the areas west and southwest of Breckenridge that in this report are included with the terrace gravels. As his work did not extend far north of Breckenridge, this was a very natural conclusion, inasmuch as these particular masses of gravel are but poorly exposed and where they adjoin the later terminal moraine along Carter Gulch they appear to have been moved to some extent by the ice and are characterized locally by a hummocky topography. Mr. Capps in conversation has agreed to the change in designation here noted.
[10] Ball, S. H., Prof. Paper U. S. Geol. Survey No. 63, 1908, pp. 84–85.



A. GENERAL VIEW OF THE GOLD RUN PLACERS FROM THE SOUTHEAST.

These, probably the most productive and extensively worked hydraulic washings in the district, are in the older hillside wash. See page 177.

B. NEAR VIEW OF A BANK IN THE GOLD RUN PLACERS.

Note the angular form of the fragments. The bank is about 40 feet high. See page 177.

detritus that have been derived from the immediately adjacent slopes by creep and by the wash of rain water or snow water in its descent to the established stream channels. Many of these deposits have been rich in detrital gold and yielded large returns to the early placer miners. Some are not definitely distinguishable as regards either age or thickness from the soil that mantles the hills to various depths; some, on the other hand, are of notable bulk and are so closely related to the terrace gravels as to suggest reference to the same general period of deposition. The distinction between the two is one of age rather than kind, and probably would be even less definite were the history of the deposits fully known. In other words, as the erosional development of the region proceeded, old detrital deposits were reworked into new and probably passed through intermediate stages whose obscure traces are very illegibly recorded in the topography of to-day, and consequently when found are likely to be assigned to the beginning or end of a cycle rather than to the intermediate place where they properly belong. It is accordingly recognized that the distinction here made between the older and younger hillside wash is perhaps unnaturally rigid. The deposits mapped as older wash (Pl. I, in pocket) are those having an extent, thickness, and range of altitude that are out of proportion to the present activity of the neighboring streams and that relate them to the physiographic and climatic conditions similar to those under which the terrace gravels were laid down. Other deposits, generally smaller, plainly related to existing ravines and distinguished from ordinary local thick accumulations of stony soil merely by their auriferous character, are regarded as younger or recent hillside wash and are given no distinctive color on the map.

DISTRIBUTION.

The principal areas of older hillside wash are along the southwest side of Gold Run and one on the south side of the Swan, just east of Delaware Flats. Both, but particularly the Gold Run deposit, have been extensively worked by the use of monitors or giants.

THICKNESS.

In Gold Run the auriferous wash is up to 40 feet thick. Most of it rests on shale, although at the upper or southeast end of the deposit the bedrock is partly porphyry. There is no distinct rock terrace, but the detrital material lies on a gentle slope and merges along its upper margin with the ordinary soil of the hillsides. The upper limit of the deposit, so far as it can be said to have a limit, is from 250 to 300 feet above the present bedrock channel of the stream draining Gold Run.

The wash of the area on the south side of the Swan rests upon an uneven surface of porphyry and shale and overlies, as has been mentioned, at least one thin deposit of terrace gravel that rests on a high rock bench. The older wash of this area attains a maximum thickness of 25 to 30 feet.

CHARACTER OF MATERIAL.

The distinguishing features of the hillside wash as compared with the terrace gravels are the angularity of its fragments and the local derivation of these. This angular character is well shown in Plate XVI, which illustrates the appearance not only of the undisturbed material but of the large fragments left after the finer material has been sluiced away. In this view the fragments are chiefly Dakota quartzite from the north spur of Gibson Hill. Some are as much as 3 feet long, but most are less than 1 foot in greatest diameter. In the bank these fragments are mingled with much soft yellow sandy clay and small angular rock particles, the whole showing rude stratification with a gentle dip corresponding in general with the slope of the bedrock. In comparison with the terrace gravels, the proportion of large rock fragments to the earthy matrix is small. The very large proportion of durable quartzite fragments in the hillside wash renders it difficult to compare the effect of weathering processes on this material with the conspicuous results noted in the terrace gravels. Where fragments of porphyry occur in the wash, however, they are generally much less decomposed than the bowlders of similar rock in the terrace gravels.

The terrace gravels are distinctively fluviatile—the deposits of powerful and persistent streams capable of moving large bowlders for long distances. The hillside wash, on the other hand, represents the action of shifting and temporary floods cooperating with alternating freezing and thawing, or wetting and drying, with disturbance of local equilibrium by the growth or decay of vegetation or by the disintegration of the rocks and with all the small but inevitable forces that tend to move loose material downhill under the stress of gravity.

RELATIVE AGE OF THE TERRACE GRAVELS AND OLDER HILLSIDE WASH.

Near the mouth of Gold Run the terrace gravels and the older hillside wash come together in such a way as to suggest contemporaneous deposition. Unfortunately, however, there are in this vicinity no good exposures of the two kinds of material, so that it is impossible to say whether the suggestion of gradation of one into the other has any real basis or whether the wash is wholly younger than the gravel and was deposited against it. In the area east of Delaware Flats some well-rounded coarse gravel, supposed to belong to the same period as the terrace gravel along the Blue, occurs at the base of the hillside wash and is accordingly older than the wash at this particular place. This fact, in connection with the comparatively undecomposed condition of the wash, indicates that it is probably all somewhat younger than the terrace gravels. How much younger can not be definitely determined, for it does not appear possible to relate the hillside wash in any definite way with the morainal deposits of the second ice advance or with any other salient physiographic event.

MORAINES.

DISTRIBUTION.

The morainal deposits of the Breckenridge district belong, so far as can be determined, entirely to the second stage of glaciation. They attain their greatest volume on the Blue and its tributaries south and west of the town of Breckenridge. Smaller masses of similar material are to be seen on French Creek, both near Lincoln and a mile farther upstream south of Farncomb Hill. Excellent examples of terminal and lateral moraines may be studied also on the forks of the Swan, but the ice-borne material in that valley barely entered the area mapped in connection with this report.

MORAINES ON BLUE RIVER.

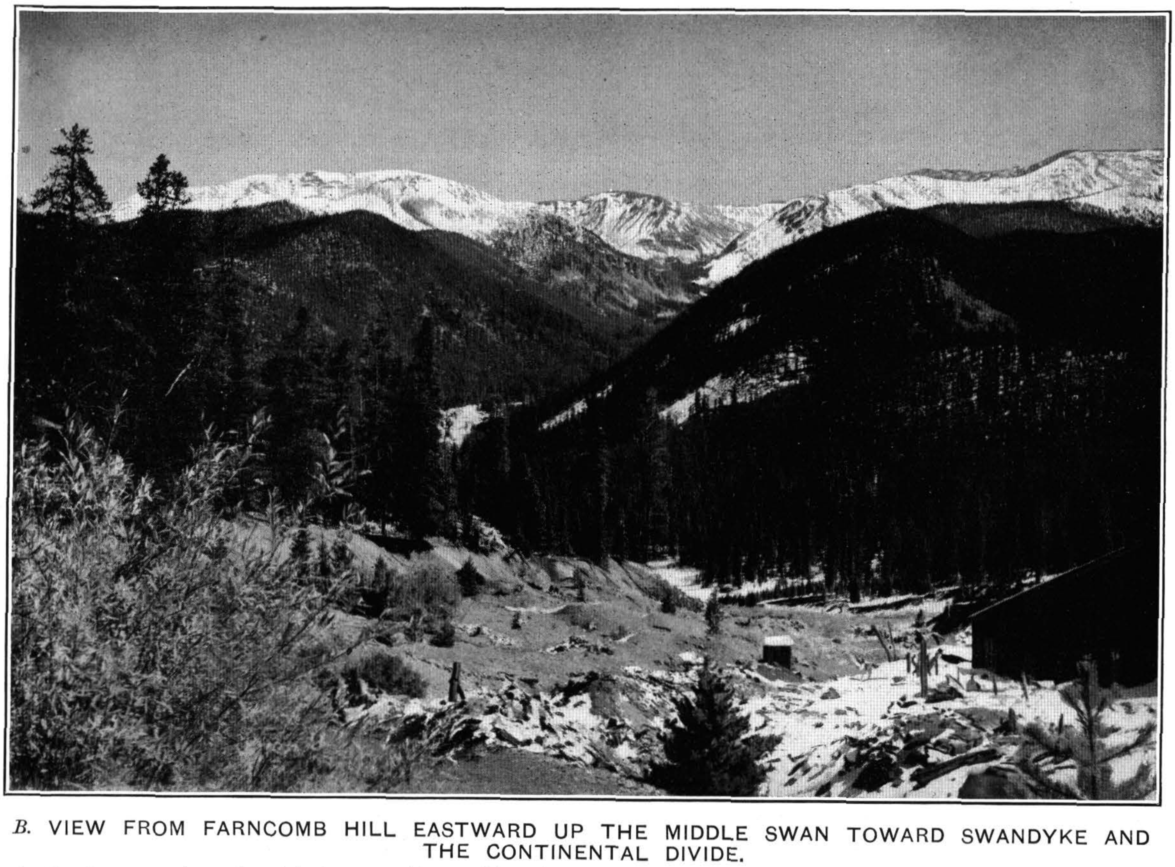
The ice of the last advance filled the valley of the Blue from the cirques at its head to the site of Breckenridge, a distance of about 10 miles, and the terminal moraine left by this glacier just south of the town is a notable feature of the valley topography. The farthest north reached by the ice appears to be marked by a morainal remnant in the form of a low ridge of bowlder till that extends northwest from the base of Nigger Hill to the vicinity of the Gold Pan shops. The sharp morainal ridge between Carter Gulch and the Blue was perhaps formed or initiated at this time of maximum ice extension.

The glacier then retreated slightly and began the formation of the main terminal moraine, whose front stretches westward across the valley from the base of Little Mountain. The main road south from Breckenridge traverses a smooth plain of low-level gravel for about a third of a mile and then makes a short ascent of about 50 feet to the top of the moraine, which shows a typical knob and kettle topography. From the road as it skirts the south edge of this lobe to descend into the recent trench that the river has cut through the moraine, or, better still, from Little Mountain, an excellent view may be obtained over the hummocky surface of the terminal moraine, which extends for fully 2 miles south of Breckenridge. (See Pl. XVII, *A*.) Beyond it is the broad upper valley of the Blue, once occupied by ice but now floored with gravels and silts deposited in front of the glacier as it retreated southward. The features of this valley that are recognized as due to glaciation have been described by Capps,[1] who calls attention

[1] Capps, S. R., Bull. U. S. Geol. Survey No. 386, 1909, pp. 77-79.

A. UPPER VALLEY OF THE BLUE, WITH TERMINAL MORAINE IN THE FORE AND MIDDLE GROUNDS.

The view is south, from Little Mountain. In the foreground is the present channel of the river through the moraine. Back of the moraine is the little area of level silt known as the Goose Pasture. Hoosier Pass is visible in the distance. See page 76.



B. VIEW FROM FARNCOMB HILL EASTWARD UP THE MIDDLE SWAN TOWARD SWANDYKE AND THE CONTINENTAL DIVIDE.

In the foreground are the old placer workings of American Gulch. The bedrock is Upper Cretaceous shale, which dips toward the pre-Cambrian rocks of the distant snow-whitened mountains. See page 15.

particularly to the fine examples of glacial sculpture displayed at the head of the Blue (Monte Cristo Gulch) and in the cirque north of Quandary Peak. He does not mention, however, the occurrence of two well-marked though low moraines of recession, each with its gently sloping train or outwash apron, which is now, of course, dissected by the present river into two lateral terraces. The road up the valley lies for much of the way on these terraces, ascending each to its head, crossing a low moraine, and dropping to the foot of the next gradual slope.

Indiana Creek finds its way into the Blue through a narrow cleft which it has cut through a mass of morainal material that once blocked its course. There is no evidence, however, that any glacier came down Indiana Gulch. The material was probably dropped as a lateral moraine and crowded into the mouth of the gulch by the main glacier that formerly occupied the vallley of the Blue.

The material of the terminal moraine consists of the unassorted angular material characteristic of such deposits. The rock fragments are chiefly of pre-Cambrian crystalline rocks from the Tenmile Range, but there is also much quartzite. At one place on the extreme south edge of the area mapped, near the head of Carter Gulch, the blocks of quartzite are so numerous as to indicate a probable outcrop of this rock through the moraine. The largest mass of transported rock noted in the terminal moraine is a fragment of gneiss east of the so-called Goose Pasture. This measured 30 feet in length, 15 feet in width, and at least 12 feet in height, a part of it being buried.

The moraines west of Breckenridge were formed by short lateral glaciers that headed in cirques near the crest of the Tenmile Range and deposited débris from the pre-Cambrian crystalline rocks over the terrace gravels.

MORAINES IN FRENCH GULCH.

The French Creek glacier advanced fully half a mile below Lincoln and left morainal deposits on both sides of the valley. That of Weber Gulch, on the south, is the more extensive and attains an altitude of 9,750 feet, or 550 feet above French Creek. The moraine north of Lincoln (see Pl. I in pocket) rises to about 9,650 feet. Probably these two masses were at one time connected by a terminal moraine across the valley, but if so, this appears to have been cut through before the end of the glacial epoch. The remaining material evidently was dumped and crowded by the ice into the two little ravines that happened to open opposite each other near the end of the glacier and probably includes also considerable detritus contributed by the ravines themselves while their mouths were blocked by the ice. As the glacier retreated up the valley whatever terminal moraine may then have existed was cut through and part of the morainal masses on the hillsides, no longer supported by the ice, slid down over the slopes against which the glacier had rested and mingled with the low-level gravels.

The material of the Weber Gulch moraine is well exposed to a depth of about 50 feet in some old hydraulic workings, but the base of the deposit is not now visible. The banks show an unstratified mixture of large and small, round and angular fragments up to 6 feet in diameter, with much earth, sand, and clay. Most of the larger blocks are quartzite or porphyry, such as might have been derived from the head of the gulch. There are many smaller fragments of shale, however, and some of these show well-preserved glacial striæ. A few of the porphyry blocks also show striæ, but this rock, owing to its coarser texture, is not so well fitted as some of the harder varieties of the shale to receive and retain glacial scratches. The material in Rich Gulch, north of Lincoln, is similar to that of Weber Gulch, but few of the fragments here exceed 4 feet in diameter and most are under 18 inches. Striated fragments of shale are abundant. The little meadow known as Lincoln Park (see Pl. V, *A*, p. 20) is due to the silting up of a short ravine behind the moraine. There was possibly a lakelet here in Pleistocene time.

The next recorded halt of the retreating end of the French Creek glacier was in the vicinity of Black and Little French gulches, south of Farncomb Hill. Here was left a terminal moraine that still retains its characteristic hummocky topography. The upper limit of morainal deposition is here, as elsewhere in the district, rather indefinite, but some material was certainly dropped on the hillsides at least 500 feet above the bottom of the valley. At the mouth of Little French

Gulch is a well-preserved morainal bench about 400 feet above French Creek with an undrained depression on its top. This material, which is largely shale with abundant striated and faceted fragments, was probably dumped into Little French Gulch from the main glacier, forming a dam through which the small present stream has cut a narrow gorge, apparently a little south of its preglacial channel.

There is much rocky detritus in the basin at the head of French Creek, but this is not definitely morainal and in large part is certainly débris that has fallen in postglacial time from the steep rocky walls against which the ice formerly exerted its supporting pressure.

Naturally, there are no fragments of pre-Cambrian rocks in any of the French Gulch moraines. Their constituent fragments are porphyry and shale with a subordinate quantity of quartzite and limestone, all derivable from the area now drained by the creek.

MORAINES ON THE SWAN.

The morainal material shown along the Swan opposite Georgia and American gulches appears to represent the farthest advance of the ice down that river valley. The moraine mapped consists of the usual coarse till with huge blocks of pre-Cambrian rock and is merely the outer edge of a terminal moraine deposited by glaciers that came down the south and middle forks of the Swan. There is a succession of hummocky terminal moraines with numerous kettles for at least a mile up the South Swan and then ground moraine up to Georgia Pass, which appears to have been itself covered with ice or névé. The Middle Swan also affords an excellent example of a typical and well-developed terminal moraine with some lateral moraines farther upstream. Scattered over the terminal moraine and on adjacent slopes are some large erratics of pre-Cambrian rocks, some being over 25 feet long. The distribution of these bowlders shows that the Middle Swan Glacier can hardly have been less than 400 feet thick near its distal end. At one time during the last ice epoch the drainage from the glacier appears to have flowed through a col on the north side of the valley near its lower end and joined the main Swan below the present mouth of the Middle Swan.

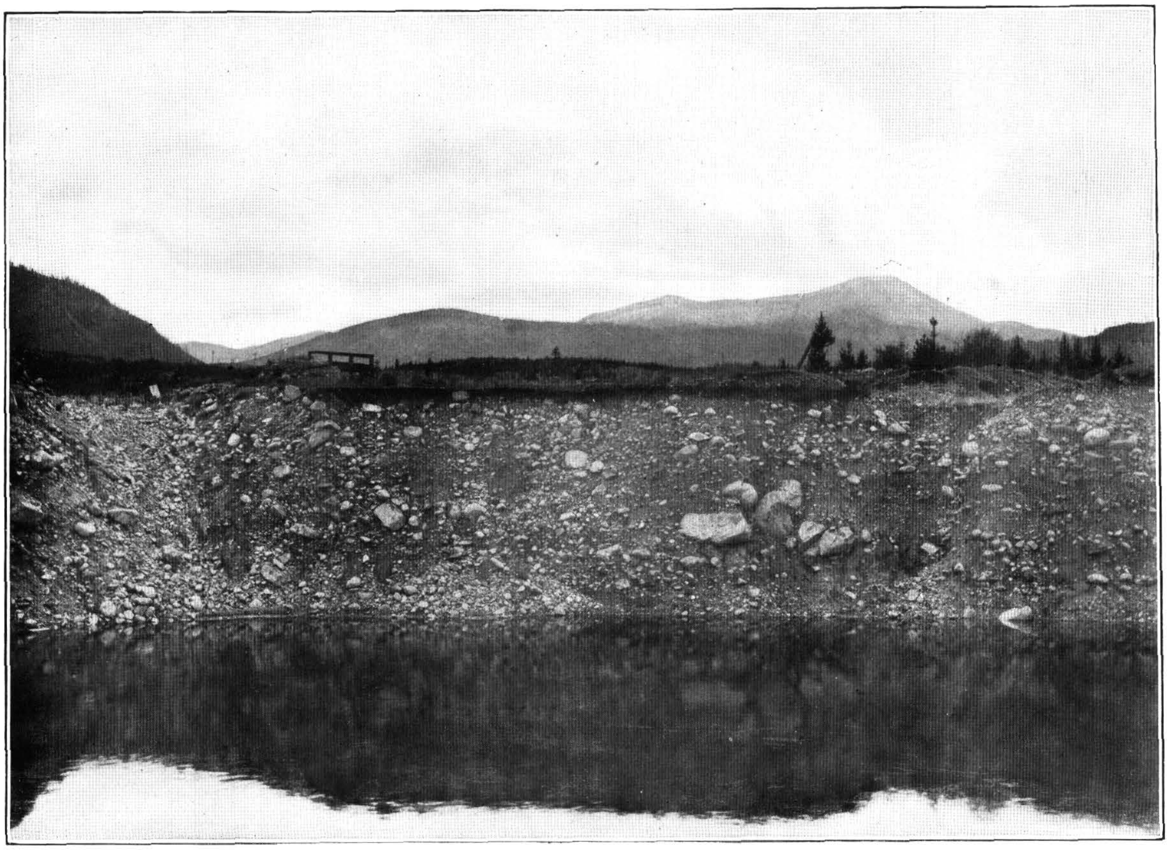
Some scattered erratics of pre-Cambrian rock lie on the shale slope north of the mouth of Georgia Gulch up to a height of 400 feet above the Swan.

LOW-LEVEL GRAVELS.

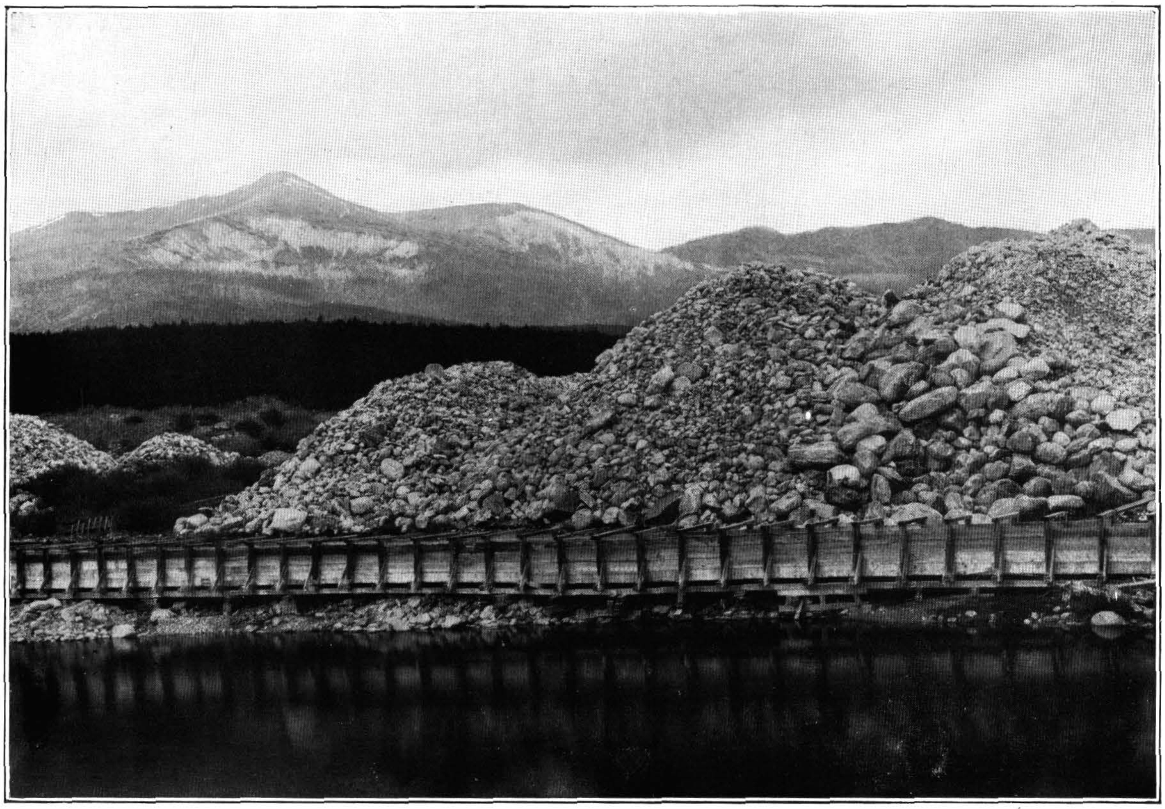
OCCURRENCE.

The low-level gravels, on which depends the present dredging industry of the district, occupy, as their name implies, the bottoms of the existing valleys. Their greatest known thickness, about 90 feet, is near the Gold Pan pit between Breckenridge and the terminal moraine. Along French Creek the depth to bedrock in the main channel, from Nigger Gulch down, ranges from 45 to 50 feet. Along the Blue, between Braddocks and the mouth of the Swan, the depth in the old channel is from 55 to 60 feet, and along the Swan, from Galena Gulch down, the maximum thickness is from 40 to 50 feet. The Blue north of the moraine, French Creek below Lincoln, and the Swan below Georgia Gulch are thus all flowing in channels aggraded many feet above the original rocky beds of these streams. This aggradation dates from the later glacial stage and the low-level gravels are valley trains, deposited by heavily overladen streams fed by the melting glaciers.

Some of the present streams have cut trenches in the low-level gravels so that their narrow alluvium-covered flood plains are distinctly lower than the even surface of the glacial outwash gravels. Near the Gold Pan pit, south of Breckenridge, the bluffs of the low-level gravel rise from 15 to 20 feet above the strip of alluvium bordering the river; about 2 miles below Breckenridge the difference in level is not over 10 feet; opposite Braddocks it is reduced to about 5 feet; and at the mouth of the Swan there is no sharp distinction between the two surfaces. The Swan, from a point a mile above Swan City to its mouth, appears to have spread its modern alluvium over the low-level gravels without trenching. Along French Creek, on the other hand, particularly in the vicinity of Lincoln, the bluffs of low-level gravel rise from 15 to 20 feet above the stream.



A. BANK OF THE GOLD PAN PIT, SHOWING CHARACTER OF DEEP GRAVELS ALONG THE BLUE.
The pit is nearly 90 feet deep, and probably not more than 20 to 30 feet of the gravel is here exposed. Note large size of bowlders and lack of stratification. See page 178.



B. BOWLDERS FROM THE GOLD PAN PIT.
Some of these are 6 feet long. See page 178.

A good idea of the generally even surface of the low-level gravels may be had from Plate XIV, *A* (p. 70), which is a view up the valley of the Blue from a point opposite the mouth of French Creek. The view shown in Plate XIII, *A* (p. 68) is one seen in looking north-northeast from the same place. In the immediate foreground is the entrenched flood-plain of the Blue, with its characteristic growth of willows; beyond this is a terrace of low-level gravel corresponding to that on which the observer stands, and rising 40 to 50 feet above this is a bench of the older terrace gravels. A similar relation of alluvium, low-level gravels, and terrace gravels is shown in Plate XIV, *B* (p. 70), which is a view west from Gibson Hill, across the valley of the Blue.

The low-level gravels attain their maximum width, about 3,000 feet, near Breckenridge and Braddocks. As will be more fully shown in the chapter on placers, they were deposited in wide-bottomed channels, unconfined by steep banks and of low gradient.

MATERIALS.

The character and state of aggregation of the material composing the low-level gravels are such important factors in dredging operations that their detailed consideration may well be deferred to the chapter on placers. It is sufficient to note here that the gravels are uncemented and are generally coarse, with hard well-rounded bowlders. In the gravels along the Blue the diameters of these bowlders range from a maximum of about 6 feet near Breckenridge to 4 feet near Valdoro. In French Gulch the large bowlders rarely exceed 3 feet in greatest diameter and are not so well rounded as those on the Blue, many of which were shaped prior to the second ice epoch. On the Swan, below Galena Gulch, the gravel is more uniform and contains fewer large bowlders than that along the Blue or in French Gulch. Coarser material, however, is found above the mouth of the North Fork of the Swan.

The low-level gravel shows no recognizable stratification and the largest bowlders are not limited to the bottom of the deposit, but may occur at any horizon. This nonassorted material is well shown in Plate XVIII, *A*, which is a view of the upper part of the gravel at the Gold Pan elevator pit. There are no places at present where the gravels can be seen below water level, but it is probable that were a series of complete sections of the gravel available for examination those farther from the moraine than the Gold Pan pit would show less chaotic deposition.

GLACIAL LAKE BEDS.

The little area of meadowland known as the Goose Pasture, partly inclosed by the terminal moraines south of Breckenridge, probably corresponds to the depression occupied by the attenuated end of the waning glacier, before it retreated definitely southward near the close of the second ice epoch. Apparently the Blue had at this stage already established its channel across the older part of the terminal moraine, so that the final retreat of the ice left only a small lake to occupy its abandoned bed behind the moraine. This presumably was soon filled. Of the character of this deposit very little could be learned. According to Mr. B. S. Revett a drill hole put down in the Goose Pasture passed through 106 feet of silt, sand, and fine gravel, but detailed records of this boring could not be found. Superficial natural exposures in the banks of Blue River show sand and gravel, the pebbles rarely exceeding 4 or 5 inches in diameter. Bedding is not apparent.

RECENT ALLUVIAL AND DETRITAL DEPOSITS.

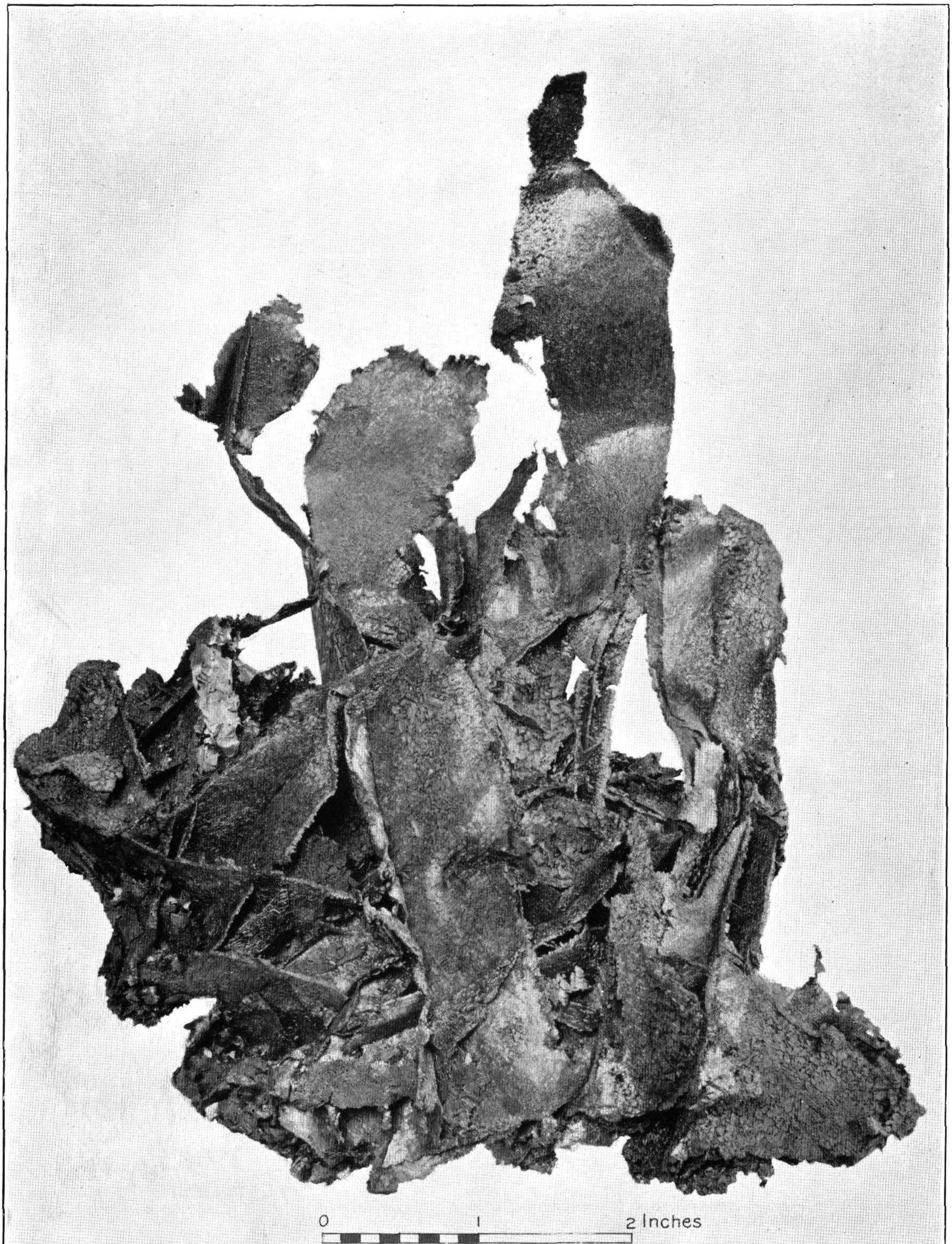
Under Recent alluvium are included the thin deposits of unconsolidated material laid down on their flood plains by the streams and streamlets of the present cycle. Here belong the meadowlands along the Swan and unimportant strips of lowland, generally clothed with willow thickets, along French Creek and the Blue. Lincoln Park is covered with alluvial soil washed from the surrounding slopes and possibly resting on older lake silts.

Here may be mentioned also the loose material, not as a rule separable from the ordinary soil of the hillsides, that in early days was washed for gold in American, Georgia, Humbug, Browns, Galena, Gibson, Nigger, and other gulches. This will be referred to again in the chapter on placers.

The residual soils are in many places so deep and so rich in vegetable matter as to afford to the geologist or prospector no reliable indication of the kind of rock beneath them, especially as in this region of former glaciation and intricate intrusion loose rock fragments are very unreliable guides to underlying structure. On such slopes the shale is likely to be particularly elusive, as was found to be the case on the lower northeast slope of Bald Mountain and on the northwest slopes of Brewery and Humbug hills. The gentle slope of Humbug Hill in the vicinity of the northwest corner of sec. 35, T. 6 S., R. 77 W., is covered with soil containing abundant fragments of quartz monzonite porphyry and seemingly derived in place from that rock. Numerous pits, however, penetrate loose porphyry detritus, in places 6 to 7 feet thick, and expose shale beneath. Presumably the shale at this locality was formerly covered by a sheet of porphyry, perhaps continuous with that now capping the crest of the hill. Erosion has cut through this porphyry to the shale but has not yet been able to remove the residual fragments of the harder rock.

There are considerable accumulations of angular rock waste at the head of French Gulch and in similar cirquelike basins outside of the mapped area. For the most part this material is ordinary postglacial talus, although it is possible that some of it was deposited during the last stages of ice occupancy. None of the material seen exhibits the remarkable features of the rock streams described by Howe in the San Juan Mountains.[1]

[1] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.



NATIVE GOLD FROM FARNCOMB HILL.

The illustration shows the mass in natural size and brings out clearly the characteristic structure of intersecting thin plates covered with the triangular crystal faces of the octahedron. Photograph by Schwartz from a specimen in the Campion collection, Colorado Museum of Natural History, Denver. See page 81.

CHAPTER VI.

MINERALOGY.

INTRODUCTORY STATEMENT.

Mineralogically the Breckenridge district, although a locality noted for the occurrence of crystalline native gold in filiform and leafy aggregates of remarkable delicacy and beauty, is not of great or varied interest. The ores in general offer little attraction to the mineralogist, and the common minerals constituting them call for no extended description. The order in which these are treated is that followed in Dana's "System of mineralogy."

NATIVE ELEMENTS.

SULPHUR.

Native sulphur is known only from the Iron Mask mine, where, intimately mixed with earthy cerusite and probably with some anglesite, it is said to have been found on the bottoms of cavities in the oxidized ore. Native sulphur probably often forms or is set free in the oxidation of sulphide ores, but, as a rule, is quickly oxidized to sulphuric acid. In this case the oxidation was incomplete.

GOLD.

CRYSTALLIZED GOLD OF FARNCOMB HILL.

Native gold occurs in the Breckenridge district both in veins and placers. The principal locality for vein gold is Farncomb Hill, whence have come the innumerable specimens of "Breckenridge gold" found in museums and private collections the world over. It is probable that from no locality equally productive has so large a proportion of the gold mined been saved from the melting pot on account of the beauty and interest of its form.

The typical gold from the narrow veins of Farncomb Hill occurs as two general varieties locally known as wire gold and leaf or flake gold. It is stated by those familiar with the traditions of the hill that wire gold is characteristic of the veins west of American Gulch and leaf gold of those east of that ravine.

The appearance of typical flake specimens is well shown in Plates XIX to XXI, representing specimens given by Mr. John F. Campion to the Colorado Museum of Natural History, Denver. The photographs from which these illustrations were made were obtained through the courtesy of Dr. W. S. Ward, curator of the museum. The largest specimen in this notable collection is about 8 inches long, 5 inches wide, and from one-fourth to three-fourths of an inch thick. The heaviest single mass ever obtained from the hill came from a tunnel on the Gold Flake vein and was found by H. J. Litten and others about the year 1887. It was jocularly named "Tom's baby" by the miners, and is reported to have weighed 13 pounds. As shown in the illustrations, the leaf gold is in exceedingly irregular masses, many of which consist of thin septa meeting at angles that strongly suggest deposition controlled in part by the cleavage planes of a rhombohedral carbonate of the calcite group. As a rule the sides of these septa and other less regular surfaces of the mass are covered with small crystal faces, generally the triangular face of the octahedron, up to about 3 millimeters in diameter. In some places these faces are irregularly crowded, distorted, and associated with planes not so clearly belonging to the octahedron. In other places the little triangular facets are in parallel orientation and suggest a regular imbrication of golden scales. Skeletal crystals are common, especially octahedrons, in which each face has a triangular depression or panel.

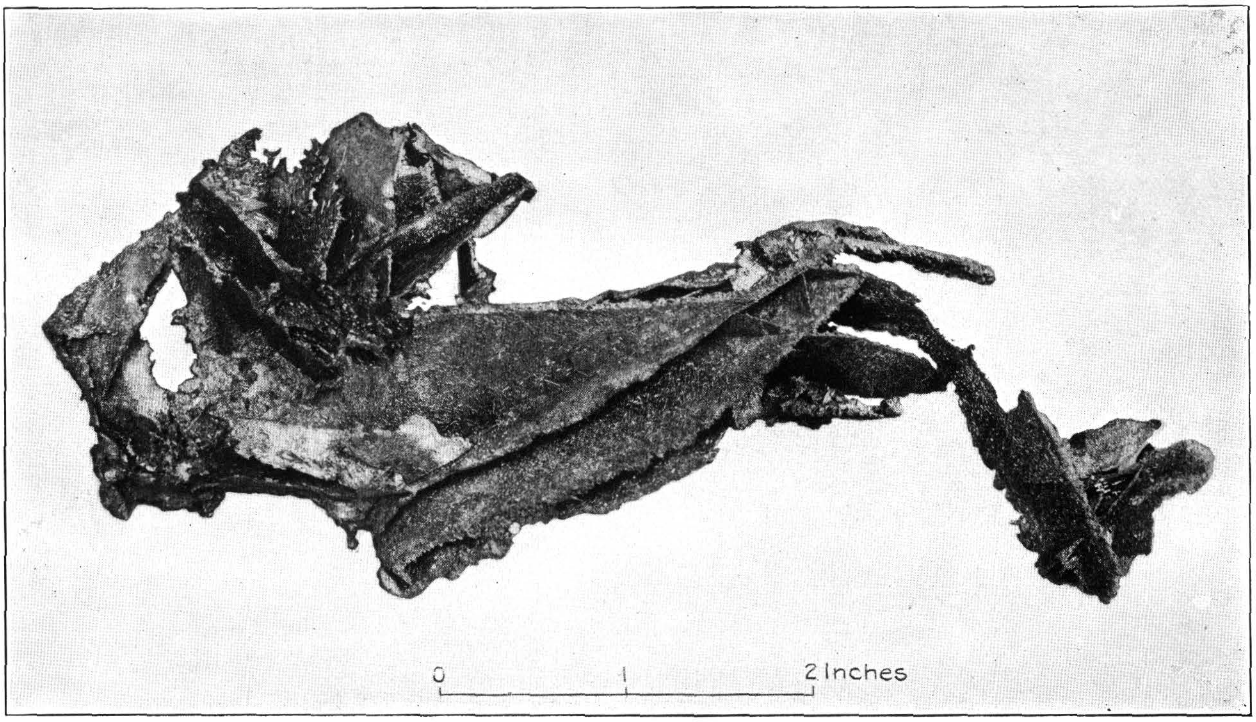
The wire gold, of which no good illustration has been obtained, is fully as beautiful as the leaf gold, but being more fragile it is not often secured in as large specimens. It consists generally of a porous mass of curved and intricately felted or tangled crystalline wires, which may individually be 3 inches or more in length. There are all gradations between coherent spongy masses of felted wires and single filaments, but as a rule, where the gold occurs in commercial quantity, it is aggregated into masses of considerable size. The wires vary greatly in thickness and shape. Some are short, stout, and rodlike; others are of hairlike slenderness. Some are longitudinally striated and resemble curved capillary shavings such as might be made with a graving tool; others are transversely ridged and are evidently chains of crystals regularly grown together, or may be regarded as one tremendously elongated crystal exhibiting the phenomenon known as oscillatory growth and illustrated familiarly by the striated prisms of slender quartz crystals; still others are rough or frosted in appearance and as seen under the microscope are covered with tiny crystal facets much as are the surfaces of the leaf gold. In cross section the wires may be square, ribbon-like, or irregular, and they may vary in thickness from point to point. Some are simple; others branch and send off little curled tendrils. In fact no wire is straight, and most of them are bent and twisted in various directions. Specimens of the wire gold, while all possessing a character distinctive of Farncomb Hill, are never monotonous. Each has its individuality of texture, crystallization, aggregation, shape, and shade of color. Notwithstanding the extreme tenuity of many of the golden filaments, these are generally so interwoven as to give the mass a coherency greater than would at first appear to belong to so delicately beautiful a mineral aggregate.

The thickness of the masses of leaf or wire gold is generally less than an inch, and, as a rule, nearly or quite equals the thickness of the vein in which they are found. The gold, however, does not occur in the clean, bright condition familiar in cabinet specimens, but is normally embedded in a reddish earthy matrix consisting largely of limonite with oxides and carbonates of copper and various earthy impurities. The removal of this matrix by baths of acid, particularly of hydrofluoric acid, is a process requiring exceptional patience and skill—qualities which, when "gold strikes" were more frequent than now, brought their possessor into much demand. So far as could be learned all the important masses of gold taken from the veins have been associated with this oxidized matrix. The association of gold and galena, however, is not unusual. Some specimens show crystals of galena implanted on or inclosing threads of gold. Some of the deepest gold found in Farncomb Hill, from stopes above the Fair tunnel, is associated with sphalerite in calcite. Wire gold in sphalerite is reported also from the I. X. L. mine, on the Swan near Browns Gulch, and some of the nuggets dredged from the gravels of French Creek show a similar association. Wire gold embedded in calcite has been obtained from the Key West vein at a depth of about 250 feet.

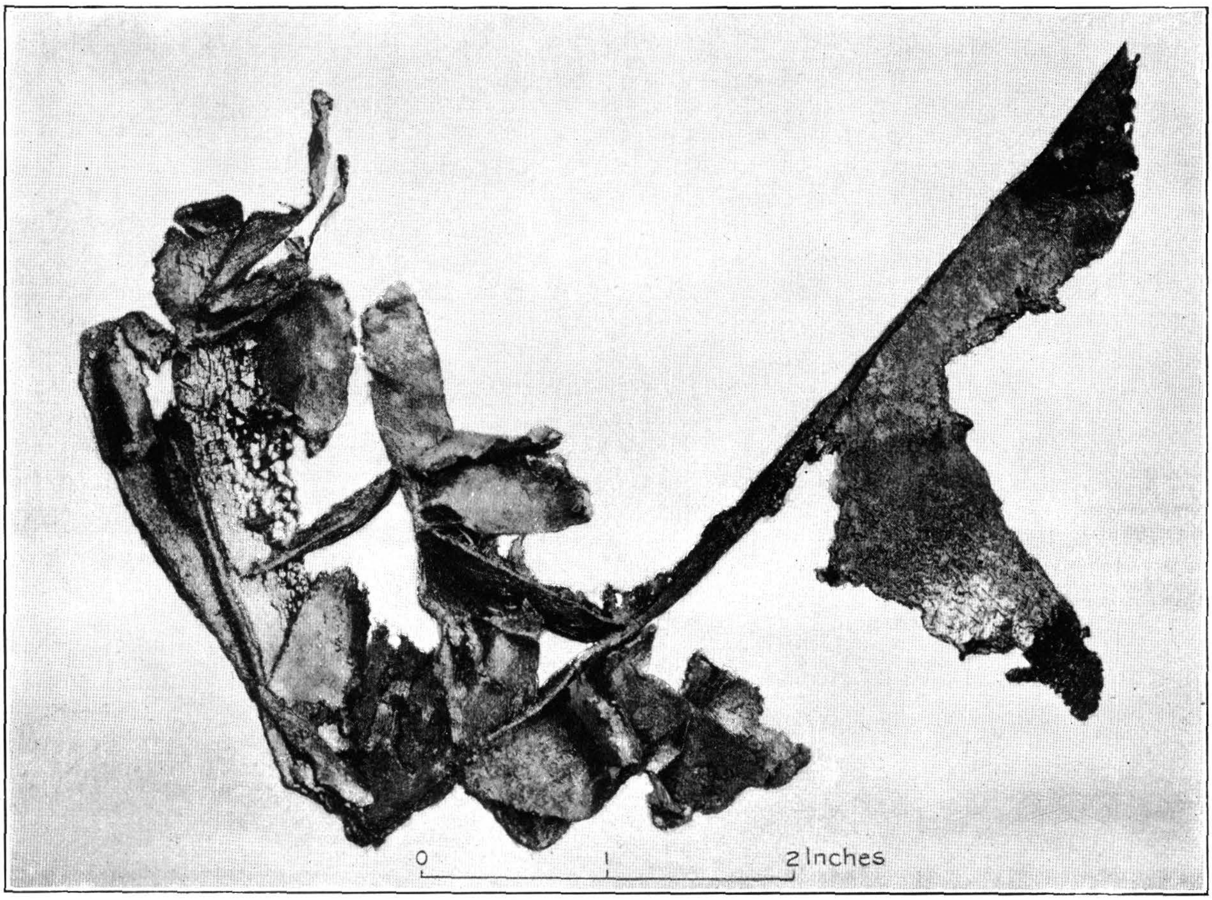
The vein gold of Farncomb Hill varies from about 750 to 900 fine, bringing from $15 to $18.50 an ounce, or more for exceptional specimens.

OTHER OCCURRENCES OF GOLD IN VEINS.

The occurrence of native gold in veins is not limited to Farncomb Hill, although no other locality in the district has produced masses equal to those of the hill in size or in beauty of form. The ore from the Jumbo and Extension mines, on the north slope of Gibson Hill, contained much free gold in the upper oxidized parts of the veins. Some wire gold associated with native silver has been found in the Juventa mine, northeast of Lincoln. Specimens of pale wire gold in galena, seen in Breckenridge collections, are said to have come from rich pockets in the generally low-grade ore of the Cashier mine in Browns Gulch, and a pale low-grade gold is reported to have been obtained from the now abandoned Helen workings, on the south side of French Gulch. Bunches of oxidized ore containing free gold have been found in the fractured Dakota quartzite at several places, particularly on Shock Hill and Little Mountain. In the latter hill was uncovered one bunch that produced $30,000 from rich limonitic ore containing native gold and silver. Handsome specimens of native gold have been taken from some of the mines in the pre-Cambrian rocks at the head of the Blue, especially from the Senator, Arctic, and Ling mines. A specimen



A.



B.

NATIVE GOLD FROM FARNCOMB HILL.

Both illustrations are natural size. The upper shows the usual intersecting plates. The lower illustrates particularly well the grouping of implanted octahedral crystals, partly in parallel orientation. Photograph by Schwartz from a specimen in the Campion collection, Colorado Museum of Natural History, Denver. See page 81.

from the Arctic mine seen in 1909 showed the gold intergrown with bismuthinite and associated with pyrite and chalcopyrite in a quartz gangue. This gold has none of the crystalline structure characteristic of so much of the metal found near Breckenridge.

The localities mentioned are by no means the only ones at which native gold in place has been found in the Breckenridge district, but they include the more important occurrences. While a highly crystalline structure is especially characteristic of the gold from Farncomb Hill, the tendency to crystallinity and to the assumption of the wire and leaf forms is a noticeable feature of nearly all the gold mined in the area here mapped.

PLACER GOLD.

The placer gold of the Breckenridge district has considerable resemblance to the lode gold and much of it, in spite of the wear to which it has been subjected in its travels, shows crystalline structure. Many of the nuggets are clearly more or less battered fragments of leaf or wire gold, although, as would naturally be expected, the nuggets in general are more solid than the specimens of wire gold from the Farncomb Hill veins, as only those pieces having initial coherence and solidity could survive the pounding to which they are subjected by the stream bowlders.

Of the character of the gold formerly washed from the Farncomb Hill placers little can now be learned at first hand, but the gold appears to have been only slightly worn. Even on the Swan at Snyder's camp, where the gravels are 27 feet deep and contain many huge bowlders, much of the placer gold retains its leafy or wiry character, although some of the nuggets are well rounded. Among the nuggets seen from these workings on the Mascot placer were some of the general size and shape of beans, and some flat scales a millimeter or so thick, 5 millimeters wide, and 15 millimeters long. Lower down the Swan the proportion of rounded nuggets increases and gold recognizable as of Farncomb Hill derivation becomes less abundant. The largest nugget found is said to have weighed 29¼ ounces Troy, and was dredged from the mouth of Galena Gulch. Such large masses, however, are wholly exceptional on the lower Swan, and the dredges now at work would probably lose over the stacker any nugget exceeding an inch in diameter. The placer gold of the lower Swan is about 770 fine.

In the deep placers of French Gulch, where dredging is now in process, the gold is coarse and nuggets 3 ounces in weight are fairly common. Many show wiry or crystalline structure. Some have adhering particles of quartz or contain gold embedded in sphalerite. They vary much in shape, but a large proportion are more or less flat or platy, the thickness of many corresponding to the width of the narrow veins in which they once lay. The fineness of the French Creek gold ranges in general from 750 to 760.

SILVER.

Native silver is not at present of common occurrence in the Breckenridge mines, and none was seen in 1909. It is said, however, to have been found in the Liberty mine, now a part of the Wellington. According to Mr. Peter Cummings, superintendent of the Wellington, this silver formed aggregates of coarse wires in a soft part of the vein. Native silver is reported also from the Juventa mine, near Lincoln, and from the placers formerly worked at the west base of Little Mountain. Although now rare, native silver probably occurred in small quantities in many of the oxidized parts of the galena-bearing lodes formerly worked.

SULPHIDES.

BISMUTHINITE.

A lead-gray mineral, called a telluride [1] by the miners, but determined by W. T. Schaller as bismuthinite, occurs in the Arctic vein at the headwaters of the Blue, associated with pyrite and native gold in a quartz gangue. The mineral is not in distinct crystals. The sulphide of

[1] No tellurides were seen in the course of the investigation of the Breckenridge district in 1909. It may be recalled, however, that Dr. R. Pearce (Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 451) found tellurium in some of the Leadville ore, and tellurides are occasionally reported by prospectors from different places along the Tenmile Range. These latter occurrences may, however, be bismuthinite.

bismuth occurs also in the I. X. L. mine with a very compact pale sulphide of iron, probably marcasite, and some pyrite, in quartz. A bismuth mineral, probably bismuthinite, has been reported also from the Wire Patch and Cashier mines.

GALENA.

The sulphide of lead is one of the commonest and most important sulphides found in the district, being exceeded in abundance only by pyrite and sphalerite. In many ores, such as those of the Wellington mine, it is the most valuable mineral constituent, and even in deposits like that of the Jessie mine, where gold and silver constitute the essential part of the output, the presence of galena is one of the best indications of good ore. Even the gold veins of Farncomb Hill and the high-grade zinc ore of the Country Boy mine are not free from this sulphide.

The relation between the presence of galena and the silver contents of the ores is close and the mineral is generally though varyingly argentiferous.

The usual form of occurrence is in moderately coarse massive aggregates. Some of the largest cleavage faces seen were in the Wellington mine and were up to 2 inches across. In that mine cavities in the ore lined with crystals of galena are abundant, generally with well-developed faces of the cube, modified by facets of the octahedron.

SPHALERITE.

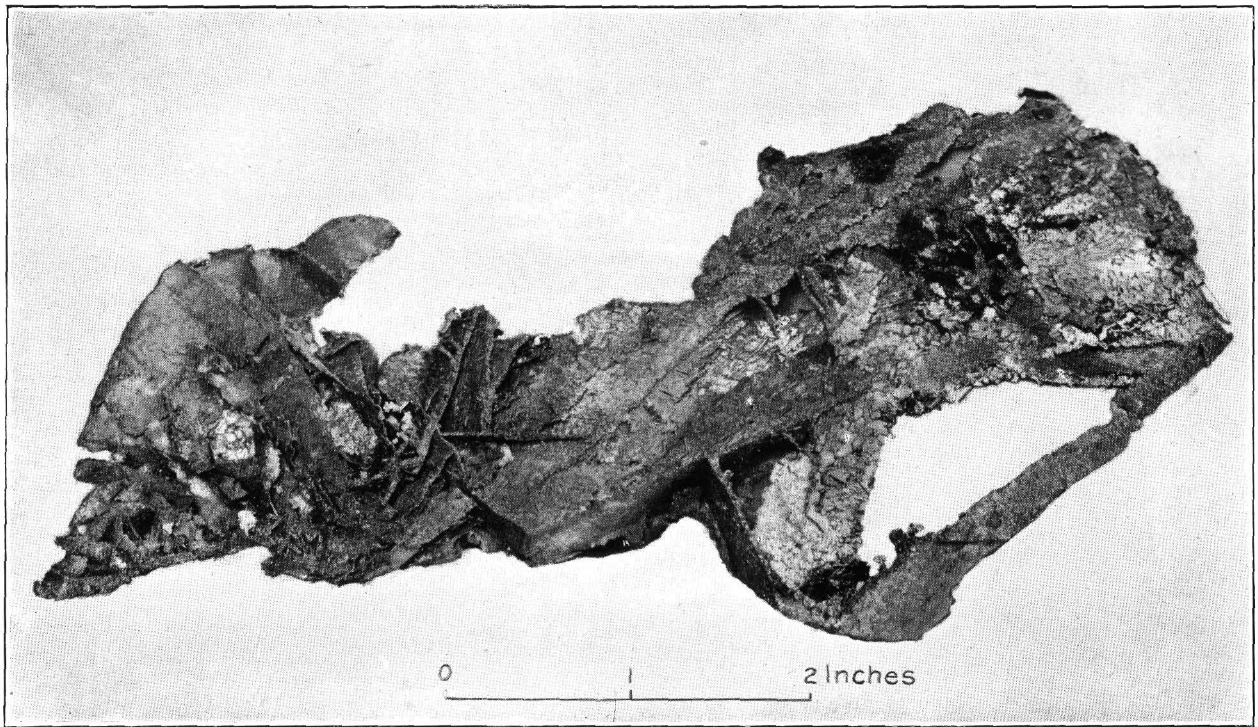
Zinc blende is an abundant and important constituent of most of the Breckenridge ores and occurs also to some extent in disseminated condition in the altered porphyries and in arkosic sediments, close to some of the ore bodies. Most of it is a nearly black variety with dark reddish brown streak, but a second and economically unimportant generation of a rosin-colored sphalerite is found in a few ores. Well-formed crystals of the dark variety are rare. The habit of the mineral is generally that of a massive aggregate in which are little vugs lined with crystal faces.

Sphalerite, nearly free from other sulphides, occurs in the Country Boy mine, which has shipped many cars of ore ranging from 47 to 55 per cent of zinc. Pure sphalerite (ZnS) contains 67 per cent of zinc. As most dark sphalerites contain from 10 to 15 per cent of iron, the best Country Boy ore evidently is nearly free from gangue and other sulphides. Sphalerite is very abundant also in the ore of the Wellington mine, in many places preponderating over the pyrite and galena, with which it is generally associated.

The frequent association of sphalerite with gold has been described in connection with that metal and probably none of the unoxidized ores of the district are entirely free from zinc blende. In the upper parts of some of the veins it alters partly to smithsonite and in the general oxidation of the ore deposits is decomposed and carried away in solution more readily than the associated galena.

CHALCOPYRITE.

Chalcopyrite is of rather wide distribution in the Breckenridge region, but, so far as is known, is not present anywhere in large quantity and is not an important ore constituent. It occurs in small irregular bunches in the pre-Cambrian schists of the northeast corner of the mapped area, but prospecting has failed to expose any bodies of commercial importance. It is common in the little veins of Farncomb Hill, where, as a rule, it is partly oxidized to limonite and malachite, and is rather sparingly present in the Wire Patch ore with pyrite, sphalerite, and galena. Careful search would probably reveal a little chalcopyrite in most of the sulphide ores of the district, but many specimens show no trace of this mineral. It is generally associated in small quantity with the metamorphic effects described on pages 93-94. It is a constituent also of the ores of the Dunkin workings on Nigger Hill, the I. X. L. mine on the Swan, and the Monte Cristo, Senator, Arctic, and other mines in the pre-Cambrian and Paleozoic rocks at the headwaters of the Blue.



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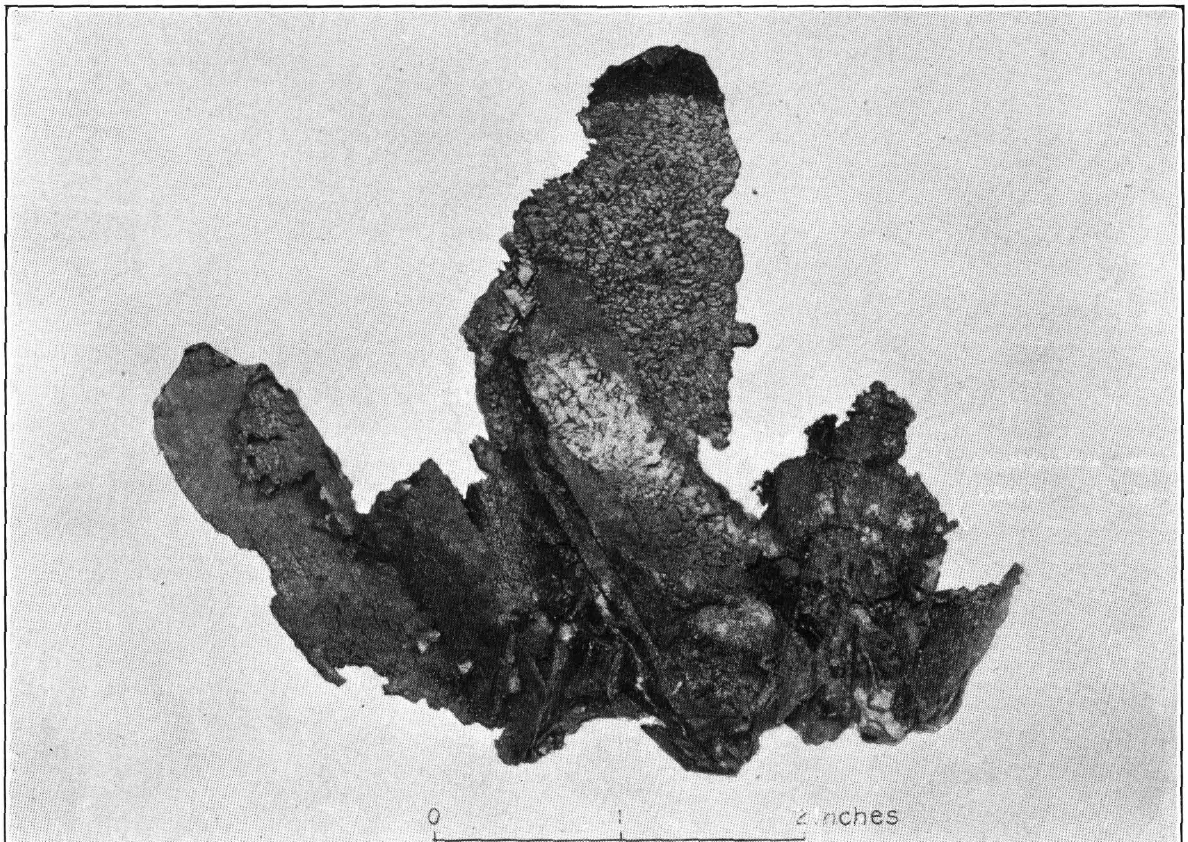


B.

NATIVE GOLD FROM FARNCOMB HILL.

Both illustrate on natural scale the size and delicacy attained by some of the crystal-coated plates. The lower figure shows octahedral crystals in parallel orientation. Photograph by Schwartz from a specimen in the Campion collection, Colorado Museum of Natural History, Denver. See page 81.

PYRITE.

The common disulphide of iron is the most ubiquitous sulphide in the district. It is a constituent of all the unoxidized ores and to a variable extent of nearly all the rocks in the region. In some ore deposits it is abundant, and, except where notably auriferous, generally lowers materially the value of the ore. At the Wellington mine the pyrite is for the most part a waste product, although in some of the middlings from the jigs, sold on their zinc contents, the pyrite is utilized for acid making. Pyrite unaccompanied by sphalerite or galena is rarely auriferous enough in this district to rank as ore.

Part, at least, of the pyrite in the wall rock of veins, and probably all of that distributed through the propylitically altered porphyries has been formed without the introduction of additional iron, by the decomposition of magnetite and femic silicates originally present in the rock.

Mineralogically the pyrite presents no features of exceptional interest. In the form of sharp simple cubes, up to about 5 millimeters across, it is abundant in the ore of the Sultana mine, at the west base of Gibson Hill, where it is associated with chlorite, magnetite, specularite, quartz, and calcite. Smaller, less regular cubes were noted in a vein cut by the French Creek tunnel, associated with much massive pyrite and some sphalerite and siderite. In the Sallie Barber mine much of the pyrite is in variously modified cubic crystals. Small irregular cubes occur also in the Wellington ore. Most of the pyrite in the district, however, is pyritohedral or in massive aggregates destitute of identifiable crystal faces. Some of the largest pyritohedrons observed are in the Wire Patch ore, several of them being 15 millimeters in diameter.

An interesting case of replacement by pyrite was seen in black calcareous shale cut by a lessee's tunnel on the Dunkin ground, on the north side of Illinois Gulch. Here the pyrite, partly in small cubic crystals and partly in compact aggregates with a suggestion of radial structure, forms small lenses parallel with the bedding of the shale. Some of these lenses end sharply at minute fissures, many of them nearly microscopic, which themselves contain a little pyrite and calcite, or other carbonate. The specimens (see fig. 9) illustrate neatly on a small scale the manner in which the shape of important replacement deposits may be influenced by preexisting fissures.

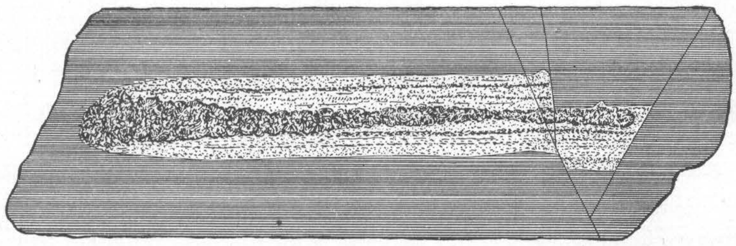


FIGURE 9.—Sketch showing replacement of shale by pyrite. Natural size. The small fissures are older than the pyrite and are crossed by its banded structure.

As is explained on page 164, the pyrite in the district was not all formed at the same time, but some ores show at least two generations.

OXIDES.

QUARTZ.

The very common mineral quartz is not an important gangue material in the Breckenridge ore deposits, and the nonsiliceous character of most of the veins is one cause of their failure to outcrop. In the veins carrying much galena and sphalerite even occasional bunches of ordinary vein quartz are rare. None was noted in the Country Boy vein and only a very little, crystallized with sulphides and siderite (or a related carbonate), was found in the Wellington vein. In the I. X. L. mine the ore consists of shattered quartz monzonite porphyry and quartzite with the interstices filled, or partly filled, with pyrite, sphalerite, galena, chalcopyrite, siderite, and quartz. The quartz is in part irregularly intercrystallized with the sulphides and in part incrusts the walls of the vugs in transparent projecting crystals of the usual form. The presence of the quartzite here had some influence in inducing the crystallization of the quartz and may have furnished some of the silica. In the Jessie mine there is a little milky quartz deposited on the walls of the countless small fissures in quartz monzonite porphyry that carry the sulphides. The quartz is not in well-formed crystals and does not project far from the walls. Many of these shapeless blebs of quartz appear to have grown upon parts of quartz phenocrysts cut by the fissure, the spots of quartz in the walls inducing the deposition of silica from the vein solutions.

In the ore bodies of the Hamilton mine, which are in quartz monzonite porphyry similar to that at the Jessie, the sulphides, especially the pyrite, are associated with some quartz gangue which in part represents the silification of crushed porphyry.

In the Puzzle and Gold Dust veins, which traverse porphyry, quartzite, and shale, the ore contains some quartz in the form of druses or cementing and partly replacing crushed rock that apparently was in the fissures when ore deposition began.

Ores more siliceous than those in the vicinity of Breckenridge occur in the pre-Cambrian rocks near the sources of the Blue, and the sulphides of the Senator and Arctic mines are in a matrix of massive vein quartz, associated in some places with a little carbonate similar to that described in the veins near Breckenridge.

Quartz is a conspicuous mineral in the quartz monzonite porphyries, occurring as bipyramidal phenocrysts, some of which are sharply bounded by crystal planes, but most of which have undergone more or less magmatic corrosion, as shown in figure 2 (p. 44).

Quartz in detrital grains is the chief material of the sandstones of the region, especially of the "Sawatch" and Dakota quartzites, in which the cement also is quartz.

HEMATITE.

The specular variety of the anhydrous ferric oxide, or specularite, occurs in small quantity with garnet, calcite, epidote, amphibole, and pyrite in altered sediments on the south slope of Gibson Hill. It is a microscopic constituent of the ore of the Sultana mine at the west base of the same hill, as shown in Plate XXII, *B*. Its associates here are magnetite, pyrite, chlorite, quartz, and some minute needles that are probably amphibole. Specularite occurs also with pyrite, sphalerite, magnetite, chalcopyrite, and small quantities of galena in the Witch Hazel vein of the Senator mine at the head of the Blue. (See Pl. XXXI, *B*, p. 160.) Massive hematite with magnetite is abundant in the dumps of some old abandoned workings in the "Sawatch" quartzite west of Hoosier Pass. The coloring matter of the bright-red "Wyoming" formation is probably hematite in greater part.

MAGNETITE.

Magnetite, or one of its alteration products, pyrite and limonite, is everywhere present in the igneous rocks as a microscopic constituent and in many places persists in the soils and sedimentary rocks derived from igneous rocks, as shown by the black sands obtained in panning. In some of the pre-Cambrian pegmatites it is a fairly abundant megascopic mineral, as may be seen on the headwaters of the Blue or at Swandyke, east of the Breckenridge district. It occurs in some of the metamorphic rocks described on pages 93–94 and in Prospect Gulch has been found in fine granular form in a matrix of earthy calcite. At the Senator mine it occurs intimately associated with specularite in an ore containing quartz, chlorite, pyrite, specularite, and chalcopyrite. (See Pl. XXXI, *B*, p. 160.) In massive form, mixed with hematite, it occurs in the upper part of veins worked many years ago in the Cambrian quartzite on North Star Mountain, west of Hoosier Pass. The dump of the Old Ironsides mine on Nigger Hill shows some magnetite in oxidized ore, associated with limonite and malachite. The mineral here appears to have been formed during the oxidation of the ore.

LIMONITE.

The hydrous ferric oxide is the usual product of the oxidation of pyrite and is found in the upper parts of all ore deposits in the district. It is the principal matrix of much of the crystalline gold of Farncomb Hill.

CARBONATES.

CALCITE.

Calcite, so far as known, does not occur in large crystals in the vicinity of Breckenridge, but in massive form it is the chief constituent of most of the limestones and as a microscopic constituent is present in nearly all of the monzonite porphyry as exposed at the surface, accompanied by chlorite, quartz, and epidote. It occurs nearly pure with garnet, epidote, and sulphides in metamorphosed calcareous sediments, as described on pages 93–94. It forms unimportant stalactitic crusts in the ore of the Wellington mine and in the Little Sallie Barber mine, where it is younger than siderite. In various states of impurity through admixture of other isomorphous carbonates it is present in small quantities in fissures and vugs in most of the lead-zinc ores. It constitutes the principal gangue mineral in the deeper parts of some of the narrow gold veins of Farncomb Hill and in unimportant sulphide-bearing stringers elsewhere in the district. In the Bowery tunnel, near Lincoln, calcite fills vugs in iron-magnesium-manganese carbonate carrying pyrite, galena, and sphalerite. In a prospect in Prospect Gulch it forms a compact, rather earthy mixture with magnetite. Finally, it is a common cementing material in the various sandstones and in microscopic or inconspicuous form is widely distributed through nearly all the rocks and ores in the district.

SIDERITE.

Pure siderite, so far as known, does not occur in the Breckenridge district. Most of the lead and zinc, however, contain subordinate quantities of white to pale buff, brown, or pink carbonate which chemical tests show to consist of the carbonates of iron, manganese, magnesium, and calcium in various proportions. Much of this material closely resembles dolomite in color, hardness, crystallization, and behavior with dilute acid, but whether any of it really belongs to this species is doubtful. The rhombohedral carbonates of the bases above mentioned constitute an isomorphous series, and apparently any mixture of them is capable of crystallizing as a single mineral not necessarily belonging to a recognized species. The essential fact to be recorded is that most of them are carbonates of iron, magnesium, calcium, and manganese, the quantities of these constituents generally being in decreasing order as named. Most are probably nearer to siderite or to the subspecies ankerite than to any other.

The siderite occurs as the filling of vugs or as small irregular veinlets in the sulphides of the lead-zinc ores, such as those of the Wellington and Country Boy mines. It is not altogether absent from deposits, like that of the Jessie mine, in the siliceous quartz monzonite porphyry, but it is not nearly so abundant in those as in the veins traversing the more femic monzonite and diorite porphyry. In some places it forms botryoidal incrustations on the sphalerite or other sulphides, the free surface of the crust showing the closely crowded points of small, imperfect rhombohedral crystals. (See Pl. XXV, p. 124.) In most of the ore bodies the carbonate is wholly subordinate to the sulphides, but in parts of some veins—the Sallie Barber, for example—similar material constitutes an abundant gangue that incloses a smaller quantity of sulphides. Much of the carbonate has a pinkish tint, due to the presence of the rhodochrosite or manganese carbonate molecule, and in some of the ore of the Wire Patch mine this color is so pronounced as to indicate a considerable proportion, perhaps over 25 per cent, of manganese carbonate. A qualitative chemical examination of this pink carbonate by W. T. Schaller showed much iron and manganese, with only a little calcium and magnesium. It possibly might be classed as a ferruginous rhodochrosite.

Some of the carbonate mixtures, which for lack of a more appropriate name are here grouped under siderite, are comparatively hard, coarsely crystalline aggregates that on fracture show broad curved cleavage faces; others are pulverulent or earthy. As described in detail in Chapter VII, the characteristic wall-rock alteration alongside of the sphaleritic veins of the district consists in great part in the introduction into the rock of a mixed carbonate, predominantly siderite. Some of the ferruginous carbonate, such as that present in vugs in the I. X. L. ore body, dissolves freely in lumps in cold dilute acid, and might therefore be mistaken for an impure calcite; but chemical tests show it to contain much iron and magnesium as well as calcite. It is probably near ankerite in composition.

SMITHSONITE.

An impure zinc carbonate containing ferrous carbonate and a trace of manganese, known to the miners as "dry bone," occurs as minute veinlets and as rough spongy bunches and incrustations of yellowish-white color in the sphalerite of the Sallie Barber mine, as illustrated in Plate XXVI, *A* (p. 126). The mineral was noted also in less abundance in the Wellington mine and is probably present in the upper parts of most of the sphaleritic ore bodies. The smithsonite forms below the water level under conditions that permit also the contemporaneous deposition of minute crystals of pyrite. It appears that acid sulphate solutions from the overlying zone of general oxidation attacked particularly the siderite associated with the sphalerite, setting free carbon dioxide, which, in turn, reacted with zinc sulphate to form smithsonite. At the same time the sulphate radicle was reduced, at least in part, and the resulting sulphur combined with iron set free from the siderite to form pyrite. The highly cavernous texture of the resulting smithsonite shows also that in this process, the forerunner of general oxidation, some material, probably both sphalerite and siderite, was removed from the ore by solution.

CERUSITE.

The carbonate of lead formed an important part of many of the lead-silver ores formerly shipped, and a little may still be seen in the upper workings of the Wellington, Minnie, Dunkin, and other mines in the southern half of the district. Good crystals, however, are rare and the carbonate ore is generally soft and earthy. Masses of crystalline material at all comparable to those found in the upper parts of the Hercules and other lead-silver mines of the Cœur d'Alene district, in Idaho, have never been found at Breckenridge.

MALACHITE.

There are no important occurrences of the green carbonate of copper in the district. It is formed in very small quantities in the oxidation of ores containing chalcopyrite on Farncomb and Nigger hills, in Muggins Gulch, and perhaps elsewhere.

AZURITE.

The blue carbonate of copper occurs sparingly in some of the oxidized ores derived from sulphide mixtures containing chalcopyrite. It was noted in the Dunkin workings, on the south slope of Nigger Hill, associated with cerusite.

SILICATES.

ORTHOCLASE.

The most conspicuous mode of occurrence of orthoclase in the Breckenridge district is as the large phenocrysts of the quartz monzonite porphyry, described on pages 44–50 and illustrated in Plate VI, *A* (p. 44). Some of these are as much as 3 inches in length, and they are generally bounded by regular crystal planes. In some places where the porphyry is weathered or softened by vein solutions the crystals resist alteration better than the rest of the rock and may readily be picked from their soft matrix or from the residual soil into which the rock has crumbled. Some of these are short, stout, simple crystals, elongated parallel with the clinoaxis and bounded dominantly by the basal pinacoid (001), the clinopinacoid[1] (010), the orthodome ($\bar{2}01$), and the prism (110), generally with the modifying faces of the unit hemipyramid ($\bar{1}10$), the clinodome (021), and the prism (130). Others, elongated, as a rule, parallel with the prism axis, are Carlsbad twins, and mostly show the same faces listed for the stouter untwinned crystals. These common habits of the orthoclase phenocrysts are nearly the same as those illustrated in figures 9 and 11 on page 317 of Dana's "System of mineralogy."

[1] For convenience of reference to Dana, the monoclinic terminology is retained. Some later works, however, treat orthoclase as triclinic with pseudomonoclinic symmetry.

The orthoclase of the porphyries is not, as a rule, perthitic, although most of the larger crystals include a few smaller ones of plagioclase. In anhedral form it is an abundant constituent of the monzonitic porphyries, especially as microscopic grains in the groundmass.

Neither ordinary orthoclase nor the variety adularia has been detected as a product of ore deposition in this district.

MICROCLINE.

Microcline is common in the pre-Cambrian crystalline rocks and in the sediments derived from them. No special study was made of it.

ANDESINE AND LABRADORITE.

The two plagioclases, andesine and labradorite, as described in Chapter III (pp. 43–62), are essential constituents of the porphyries. Most of the plagioclases of these rocks are near the dividing line between andesine and labradorite.

HYPERSTHENE.

Orthorhombic pyroxene, probably hypersthene, is a minor original constituent of some of the dioritic porphyries and was observed microscopically in some of the fresher specimens from the Wellington mine. It readily undergoes decomposition and is not likely to be found in any but the freshest of the more femic porphyries as exposed in deep tunnels or crosscuts. It presents no unusual features.

AUGITE AND DIOPSIDE.

A nearly colorless monoclinic pyroxene is a constituent of some of the fresher and more femic monzonite porphyries. It is rarely present in specimens collected from natural outcrops, owing to its ready decomposition to calcite, chlorite, and epidote.

AMPHIBOLE.

Common hornblende or one of its alteration products is a constituent of the monzonitic porphyries, as described in Chapter III (pp. 51–53), where some of its peculiarities are discussed. A dark-green amphibole occurs also in garnetized sedimentary rocks on the south slope of Gibson Hill, as noted on page 93, and a similar mineral in very small acicular crystals is a constituent of the ore of the Sultana and neighboring tunnels.

GARNET.

A brown garnet is fairly abundant at many localities in the district where metamorphism of the kind described on pages 93–94 has taken place, especially on the south slope of Gibson Hill, between Summit and Browns gulches, and in the vicinity of the Nebraska prospect, on the south side of French Gulch. No large, well-formed crytals have been seen. The material is granular, some being rather friable, but most of it being a hard, compact garnet rock. No chemical analysis of this material has been made, and it is not known whether it is essentially a calcium-aluminum garnet (grossularite) or a calcium-iron garnet (andradite). The garnet is generally associated with calcite, epidote, quartz, and sulphides, especially with pyrite, chalcopyrite, and sphalerite. Less common or abundant associated minerals are specularite and amphibole. Garnet is often puzzling to prospectors, who sometimes mistake it for cassiterite or "tin," sometimes for a mineral supposed to contain rare earths.

Under the microscope most of the Breckenridge garnet shows anomalous birefringence.

ZIRCON.

Zircon occurs in the Breckenridge district only as an unimportant microscopic constituent of the porphyries.

EPIDOTE.

Epidote, associated with chlorite and calcite, is of common occurrence, chiefly as a microscopic constituent, in the porphyries, where it has resulted from the alteration of the femic minerals. It is present also in sediments modified by contact metamorphism, as described on pages 93–94. Here its association is commonly with garnet, calcite, hematite, and sulphides.

ALLANITE.

The occurrence of allanite as an accessory constituent of the porphyries is described in Chapter III (pp. 44–50). It is nowhere abundant and has been seen only in small crystals, generally anhedral.

MUSCOVITE (SERICITE).

The minutely foliated variety of muscovite known as sericite is a common product of the alteration of rocks by vein-forming solutions as described on pages 94–99. It is especially abundant in the altered quartz monzonite porphyry, as, for example, near the Jessie mine. The fine scales of this mineral are microscopic in size and present no exceptional characteristics.

Ordinary muscovite in the form of detrital flakes is very abundant in the pre-Dakota sediments. It is an important constituent also of the pre-Cambrian schists, gneisses, and granites whence the micaceous sediments were derived.

BIOTITE.

Common black mica is an important mineral in the monzonitic porphyries. In many of these it is altered to chlorite and epidote. Further notes on its characteristics will be found in Chapter III (p. 51).

CHLORITE.

Chlorite is a common alteration product of the femic minerals in the porphyries of the district and gives to these rocks, especially to the calcic varieties, the greenish color characteristic of their surface exposures. It is not as a rule closely associated with the ores except those intimately connected with the type of metamorphism described on pages 93–94, although it is present in the veins of the Senator mine associated with quartz, pyrite, specularite, and carbonate, as noted on page 159 and shown in Plate XXXI, *B* (p. 160). In the ore of the Sultana and Fox Lake mines chlorite is an abundant microscopical constituent associated with quartz, calcite, pyrite, hematite, and magnetite. (See Pl. XXII, *B*, p. 92.)

KAOLINITE.

Kaolinite is nowhere abundant in association with the ores. It occurs, however, as a product of weathering in some of the porphyries, particularly those in which sericite has been formed.

CHRYSOCOLLA.

The hydrous silicate of copper does not occur in any important quantity in the Breckenridge district. A very little of this mineral was noted in some oxidized lead-silver ore from lessee workings on the ground of the Dunkin Mining Co., on Nigger Hill.

TITANOSILICATES.

TITANITE.

Titanite is a fairly abundant microscopical constituent of the porphyries, particularly of those in which the crystallization approaches the granitic texture.

PHOSPHATES.

APATITE.

Apatite is known in the Breckenridge district only as a minor microscopic constituent of the igneous rocks.

SULPHATES.

BARITE.

Barite is not a common mineral in the Breckenridge ores, but occurs sparingly in aggregates of imperfect platy crystals in small veinlets in the sulphides of the Wellington mine and in similar crystals associated with siderite and implanted on pyrite and sphalerite in the Rose of Breckenridge mine. Its formation was later than that of the mass of the ore in which it occurs.

GYPSUM.

In pulverulent form, the hydrous sulphate of calcium was said by a prospector, who brought some in for determination, to be found in small quantities in a prospect tunnel near the head of French Gulch, as a sediment left by the melting of ice during the summer. This mineral occurs in small quantities also in the black shale of the Gold Dust claim, in Dry Gulch, and as films or flat-stellate clusters of minute crystals in the cleavage planes of the shales of Farncomb Hill. In all three localities it is probably formed by the action of the sulphuric acid from weathering pyrite upon calcium carbonate in the adjacent rocks.

PLATE XXII.

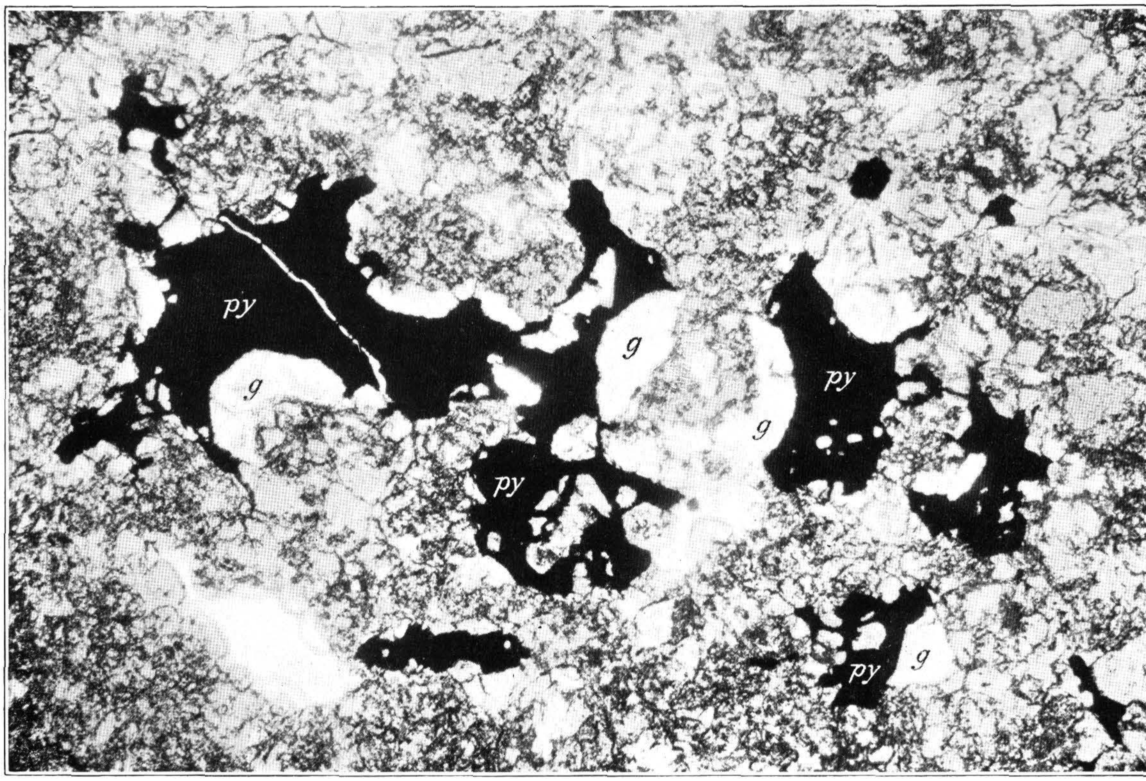
PHOTOMICROGRAPHS OF METAMORPHOSED SEDIMENTARY ROCKS.

A. Garnet-epidote rock with sulphides. South slope of Gibson Hill. × 40.

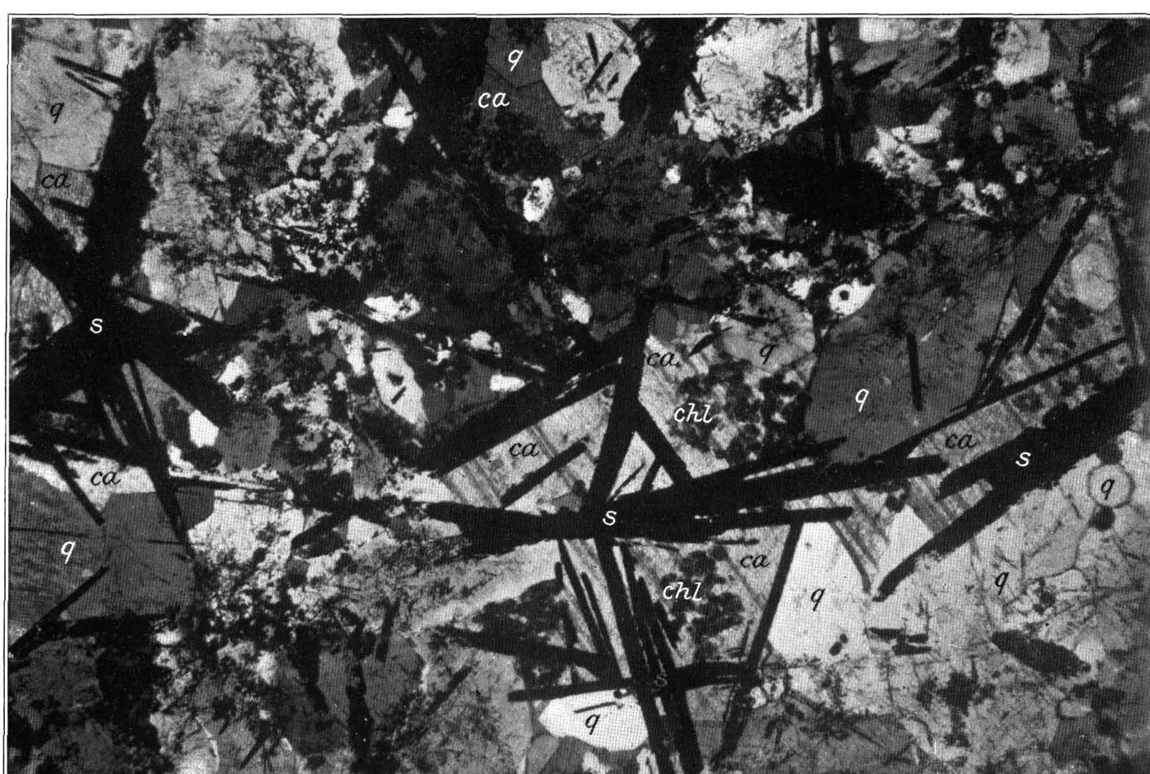
Described on page 93. py, Pyrite; g, garnet. Most of the rock is a fine mixture of garnet, epidote, calcite, and quartz. The pyrite is in part at least younger than the garnet and is contemporaneous with the calcite.

B. Ore. Fox Lake tunnel, west base of Gibson Hill. × 40. Nicols crossed.

Described on page 94. Section shows chiefly specularite (s), quartz (q), calcite (ca), and chlorite (chl). With these is commonly much pyrite. The rock is decidedly magnetic and some of the opaque grains are presumably magnetite.



A.



B.

PHOTOMICROGRAPHS OF METAMORPHOSED SEDIMENTARY ROCKS.

CHAPTER VII.

METAMORPHISM.

SCOPE OF CHAPTER.

Under the heading "Metamorphism" will be described alterations in the rocks due to igneous intrusion, ore deposition, and deep weathering, especially those changes effected in the wall rock by ore-bearing solutions. Most of the pre-Cambrian rocks also are metamorphic, but their alteration dates from a period long anterior to the formation of the ores, and was effected by forces active over regions so wide that discussion of these ancient changes would be inappropriate in a study concerned, like the present one, primarily with the later chapters in the geologic history of a small area.

METAMORPHISM CONNECTED WITH THE PORPHYRY INTRUSIONS.

The larger masses of intrusive porphyry, as shown in Chapter IV (pp. 63–71), in spite of their great irregularity, have generally the form of sheets or sills. It is well known that intrusive bodies of this kind are not ordinarily associated with pronounced contact metamorphism, and the porphyries of Breckenridge are no exception to this general rule. The rock alongside the eruptive may be shattered and, where contacts are exposed, may show some variation from its normal color or hardness, but there is rarely any development of new minerals or textures. Nevertheless, although the porphyry masses are not uniformly bordered by metamorphosed rock, there are places in the district where the sedimentary rocks have undergone modification of a kind usually regarded as due to igneous intrusion. These local areas of metamorphism, however, are not necessarily in contact with porphyry, so far as surface exposures show, and are not all demonstrably contact effects. They are thought to mark places where, during the epoch of intrusion, hot vapors or solutions, escaping perhaps not from the now visible sheets but from deeper magmatic sources, found their way through the sedimentary beds and reacted upon certain strata that were particularly susceptible to metamorphism. Between these solutions and their effects on the one hand and ore deposition on the other, there is probably no definite line of demarcation.

One place illustrating this local metamorphism is the south slope of Gibson Hill, where, in beds belonging to the Dakota, some blanket-like ore deposits, formerly worked on a small scale, are associated with bunches and lenses of garnetized rock. One mass of garnet-epidote rock containing a little specularite outcrops on the road a few hundred yards west of Gibson Gulch. Its stratigraphic relations are not clear, but it probably was at one time a lenticular bed of impure limestone in the quartzite. Lower down the slope dumps of the abandoned Bullion King and adjacent tunnels, which cut beds only a short distance above the pre-Cambrian and possibly "Wyoming" rather than Dakota, contain much garnetized material. For the most part this is altered calcareous shale and all gradations may be observed between hard cherty gray-green shale, spotted here and there by small bunches of garnet, to solid masses of brown garnet-epidote rock which, together with these two predominant minerals, contains some calcite and nests of dark-green amphibole in slender prisms, with sulphides, mainly pyrite and chalcopyrite. The microscope shows that the sulphides probably crystallize a little later than most of the silicates. (See Pl. XXII, *A*, p. 92.) Associated with the garnetized shale on the dumps is some dark micaceous shale, which is not noticeably metamorphosed, and some pebbly quartzite, which overlies the shale and contains some garnet. On the whole, the material on these dumps indicates metamorphism of considerable local intensity, but there is no contiguous body of porphyry visible to whose action it can be directly assigned.

A similar garnetized calcareous shale occurs between Summit and Brown gulches in a mass of Upper Cretaceous shale that is surrounded by quartz monzonite porphyry. Here there is no difficulty in accounting for the metamorphism as in general an effect of the intrusion of the porphyry, although it is not clear why this particular locality should exhibit more change than similar shale elsewhere shows close to the same porphyry. The explanation probably is that the metamorphism described is not so much a function of mere proximity to the porphyry as it is of channels or courses along which emanations from the solidifying igneous masses escaped, and of the chemical character of the rock affected.

The nearly horizontal blanket deposits exploited in past years in the Sultana, Fox Lake, and other tunnels along the west base of Gibson Hill are associated with decided metamorphism of the "Wyoming" beds in which they occur, just above the pre-Cambrian. The obvious results of the metamorphism are a dark-green color and an abundance of disseminated pyrite. The microscope shows that the arkosic grits or sandstones have been changed to almost wholly recrystallized aggregates of quartz, calcite (probably with admixture of other isomorphous carbonates), chlorite, pyrite, and, in some places, magnetite. The magnetite, while partly in the usual granular form, occurs also in clustered lamellar aggregates intergrown with the calcite and quartz, as shown in Plate XXII, *B* (p. 92). Where the magnetite is abundant the altered rock is nearly black.

Another locality of decided local metamorphism is on the north side of Black Gulch, a ravine opening into French Gulch above Lincoln. Here, as shown in the workings of the Nebraska mine, some calcareous beds in the Upper Cretaceous shale are altered in part to garnet, calcite, and pyrite; in part to dark, compact, heavy material containing much magnetite and pyrite; and in part to pale green-gray cherty rocks containing garnet, epidote, chlorite, calcite, quartz, specularite, and pyrite in various proportions. The pyrite is partly disseminated and partly crystallized with chalcopyrite in small irregular veinlets. Some of the dark material rich in magnetite has been shipped as a gold ore.

Other examples of metamorphism similar to those described might be cited from different parts of the district, but the occurrences mentioned are thought to be sufficiently illustrative of this sporadic kind of alteration.

METASOMATIC CHANGES IN WALL ROCK OF ORE DEPOSITS.

GENERAL CONSIDERATIONS.

That the occurrence of ore is generally associated with changes in the character and appearance of the adjacent rock is a widely recognized fact and one often turned to use by the prospector, who learns to avail himself of the visible signs of alteration as an aid in his search. Ordinarily the change is most noticeable in igneous rocks, particularly in that very large class to which the presence of femic (ferromagnesian) silicates imparts originally some shade of gray. Under the influence of solutions active in ore deposition these dark silicates are as a rule decomposed, their iron in part recombines as pyrite, light-colored minerals such as sericite, quartz, carbonates of the alkaline earths, and alunite are formed, and the rock so changed is generally softer and of lighter color than before. Even where the alteration results in no conspicuous modification of color and texture, it may nevertheless often be detected by chemical and microscopical means, for there are few wall rocks chemically so inert as not to be influenced in some degree by the reactions involved in the transportation and precipitation of ore constituents. The nature of this effect affords one way of learning something of the character of these solutions, for it is as surely a record of their work as is the ore itself. In this branch of investigation, however, it is necessary, just as in the study of the ores, to guard against crediting a certain result to a single process when in reality it may record the superposition of a later process, such as downward enrichment, upon another and earlier deposition.

ALTERATION OF MONZONITE PORPHYRY OF THE WELLINGTON MINE.

SELECTION OF MATERIAL.

In the Wellington mine, near the east end of the Oro level, there was in 1909 a good opportunity of studying the alteration of the country rock near the east vein, which is reached from the hanging-wall side by a crosscut from the fresh diorite porphyry (Br. 217) described with a chemical analysis in Chapter III (p. 55). The part of the level whence the specimen came is about 350 feet below the surface. Although this is beyond the reach of oxidizing water, specimens from greater depth would have been preferable for this purpose could they have been obtained in the district. On the other hand, decidedly favorable features of this locality for comparisons of the kind to be undertaken are the very uniform character of the fine-grained porphyry and the opportunity of studying changes and collecting specimens along a single crosscut which passes directly from fresh rock into the vein, here about 5 feet wide, with fairly definite walls along which there is not much gouge. The vein of this place, moreover, contains only a small quantity of galena and does not appear to have been notably enriched by downward-moving solutions. The specimen (Br. 217) of which an analysis and description have been given in Chapter III (p. 55) was taken 25 feet from the vein. The constituent minerals are almost perfectly fresh, although there is a little carbonate along microscopic fractures.

At a distance of 10 feet from the vein another specimen (Br. 215) was collected. At 20 feet from the vein the rock is still dark gray and essentially unaltered; but from there on it becomes lighter in shade, and at 10 feet is pale gray to buff in color, shows no dark silicates, and contains much very finely disseminated pyrite in crystals barely visible with the naked eye. Minute fissures (avoided in preparing the sample for analysis) contain pyrite, sphalerite, and galena, and here and there a speck of sphalerite can be detected with a lens in the body of the rock. Under the microscope the rock, while retaining faint traces of its original texture, is seen to have been changed into a fine aggregate of carbonate, sericite, and quartz, with a little pyrite and sphalerite. The only original constituent remaining is apatite. The carbonate is not calcite, but has the appearance of siderite or dolomite. There are also some specks of cloudy yellowish material resembling leucoxene.

Another specimen (Br. 214), collected a few inches only from the vein, is light gray and shows abundant tiny specks of pyrite, sphalerite, and galena disseminated throughout its mass and disposed along microscopic fractures. Under the microscope this rock differs from the one just described only in the greater abundance of the sulphides. (See Pl. IX, p. 52.)

COMPARISON OF CHEMICAL ANALYSES.

Chemical analysis shows the three varieties of rock to have the compositions given in columns 1, 2, and 3 of the following table:

Table showing chemical alteration of diorite porphyry.

	1	2	3	1a	2a	3a	4a	4b	5a	5b	6a	6b
SiO_2	57.35	49.59	46.62	158.46	141.68	136.59	−16.78	−21.87	− 10.59	− 13.80	−6.04	− 7.87
Al_2O_3	16.29	14.91	12.66	45.01	42.60	37.09	− 2.41	− 7.92	− 5.35	− 17.60	− .87	− 2.85
Fe_2O_3	3.15	.52	Trace.	8.70	1.48		− 7.22	− 8.70	− 91.90	− 100.00	−2.60	− 3.13
FeO	4.36	10.46	[a] 11.15	12.05	29.88	32.66	+17.83	+20.61	+ 147.97	+ 171.04	+6.42	+ 7.42
MgO	2.41	2.02	4.02	6.66	5.77	11.78	− .89	+ 5.12	− 13.34	+ 76.88	− .32	+ 1.84
CaO	5.66	1.96	1.55	15.64	5.60	4.54	−10.04	−11.10	− 64.19	− 70.97	−3.61	− 4.00
Na_2O	4.50	1.33	1.35	12.43	3.80	3.95	− 8.63	− 8.48	− 69.43	− 68.22	−3.11	− 3.05
K_2O	3.39	3.51	1.68	9.37	10.03	4.92	+ .66	− 4.45	+ 7.04	− 47.49	+ .24	− 1.60
H_2O-	.15	.16	.31	.41	.46	.91	+ .05	+ .50	+ 12.19	+ 121.95	+ .02	+ .18
H_2O+	.70	3.17	3.41	1.93	9.06	9.99	+ 7.13	+ 8.06	+ 369.43	+ 417.61	+2.54	+ 2.90
TiO_2	1.07	1.03	1.01	2.96	2.94	2.96	− .02		− .67			
ZrO_2	Trace.	None.	None.									
CO_2	.46	9.40	11.48	1.27	26.86	33.63	+25.59	+32.36	+2,014.96	+2,548.03	+9.21	+11.65
P_2O_5	.70	.47	.50	1.93	1.34	1.46	− .59	− .47	− 30.57	− 24.35	− .21	− .17
FeS_2	.09	.36	1.99	.25	1.03	5.83	+ .78	+ 5.58	+ 312.00	+2,232.00	+ .28	+ 2.01
ZnS	None.	Trace.	.97			2.84		+ 2.84				+ 1.02
PbS		Trace.	.52			1.52		+ 1.52				+ .55
Cr_2O_3	None.		None.									
V_2O_3	Trace.											
NiO	None.	None.	None.									
MnO	.12	1.10	.92	.33	3.14	2.69	+ 2.81	+ 2.36	+ 851.52	+ 715.15	+1.01	+ .85
BaO	.10	.07	None.	.27	.20		− .07	− .27	− 25.92	− 100.00	− .02	− .10
SrO	.05	Trace.	None.	.14			− .14	− .14	− 100.00	− 100.00	− .04	− .05
Li_2O	None.	None.	None.									
Rare earths	None.											
	100.55	100.06	100.12	277.81	285.87	293.36	+ 8.06	+15.55			+2.90	+ 5.60
Specific gravity:												
Mass	2.763	2.857	2.930									
Powder [b]	2.799	2.874	2.940									

[a] Uncertain owing to presence of ZnS.

[b] At 25° C. crushed to go through 100-mesh.

1. Chemical analysis of fresh diorite porphyry, 25 feet from vein, Wellington mine. W. T. Schaller, analyst.
2. Chemical analysis of altered diorite porphyry, 10 feet from vein, Wellington mine. W. T. Schaller, analyst.
3. Chemical analysis of altered diorite porphyry, less than 6 inches from vein, Wellington mine. W. T. Schaller, analyst.
1a. Constituents in grams in 100 cubic centimeters of fresh rock.
2a. Constituents in grams in 100 cubic centimeters of partly altered rock.
3a. Constituents in grams in 100 cubic centimeters of most altered rock.
4a. Gain or loss in grams of each constituent in the first stage of alteration of 100 cubic centimeters of fresh rock.
4b. Total gain or loss in grams of each constituent at the complete alteration of 100 cubic centimeters of fresh rock.
5. Gain or loss in percentage of original mass of each constituent—a, in partly altered rock; b, in fully altered rock.
6. Gain or loss in percentage of total original rock mass—a, in partly altered rock; b, in fully altered rock.

Direct comparison of analyses of fresh and altered rock does not as a rule show accurately what has taken place during alteration; it is necessary to take into account the density or specific gravity and the porosity of the rocks compared. An analysis, for example, may be regarded as representing in grams the weight of each constituent in a mass of rock weighing 100 grams. Obviously if the altered rock, to take an extreme case, is only half as dense as the fresh rock, the analysis of the altered rock will give the constituents contained in a mass of twice the volume of the initial rock or will represent the alteration of a mass of fresh rock weighing 200 instead of 100 grams. Consequently to show the actual gains and losses of the several constituents the percentage figures in the analysis of the altered rock would have to be halved in order to compare them with the corresponding figures in the original analysis of fresh rock. So great a difference in density as that postulated for the sake of illustration scarcely ever exists; nevertheless the difference is rarely negligible.[1]

There is no evidence that the present alteration has caused any general swelling or contraction of the rock mass as a whole. Comparison of the determinations of specific gravity made with hand specimens and with rock powder shows that the rock becomes slightly less porous and decidedly heavier with the progress of alteration. Of the fresh rock a fragment weighing

[1] For a full and excellent discussion of this subject see Lindgren, Waldemar, Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 591-601. Throughout this paper "cubic meter" should read "cubic decimeter."

219.69 grams in air has a specific gravity of 2.763 as a whole and of 2.799 in powder. A simple calculation from these data gives a pore space of 1.4 per cent. Although the rock is not noticeably porous as seen under the microscope, the actual percentage of submicroscopic pore space is probably a little greater than that found, as not all the pores are opened by crushing the rock

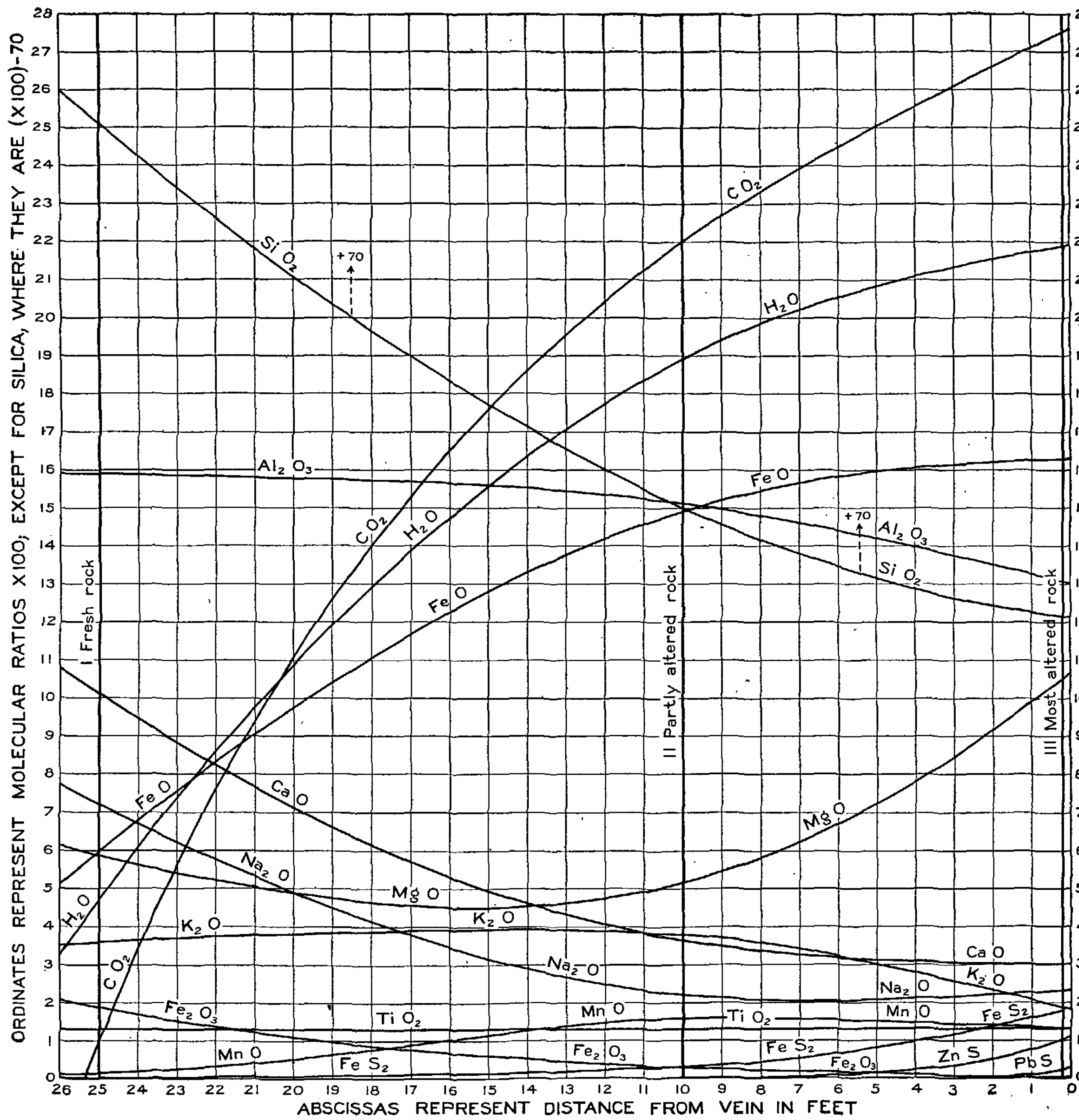


FIGURE 10.—Diagram showing alteration of diorite porphyry by vein-forming solutions.

to powder. Of the altered rock 10 feet away from the vein a fragment weighing 402.37 grams in air has a specific gravity of 2.857 as a whole and of 2.874 in powder. These figures give a porosity of 0.5 per cent. Of the altered rock close to the vein a fragment weighing 169.11 grams in air has a specific gravity of 2.930 as a whole and of 2.940 in powder. From this is deducible a porosity of a little over 0.3 per cent.

The most instructive kind of comparison between fresh rock and altered rock is one that will show quantitatively what constituents have been added to or subtracted from a known volume of the fresh material in the course of the change. Chemical analyses as ordinarily expressed represent the composition of equal weights of material. Inasmuch as there has in this case been no perceptible change in total volume and as the summation of each analysis is very close to 100, the multiplication of the figures of each analysis by the figures representing the specific

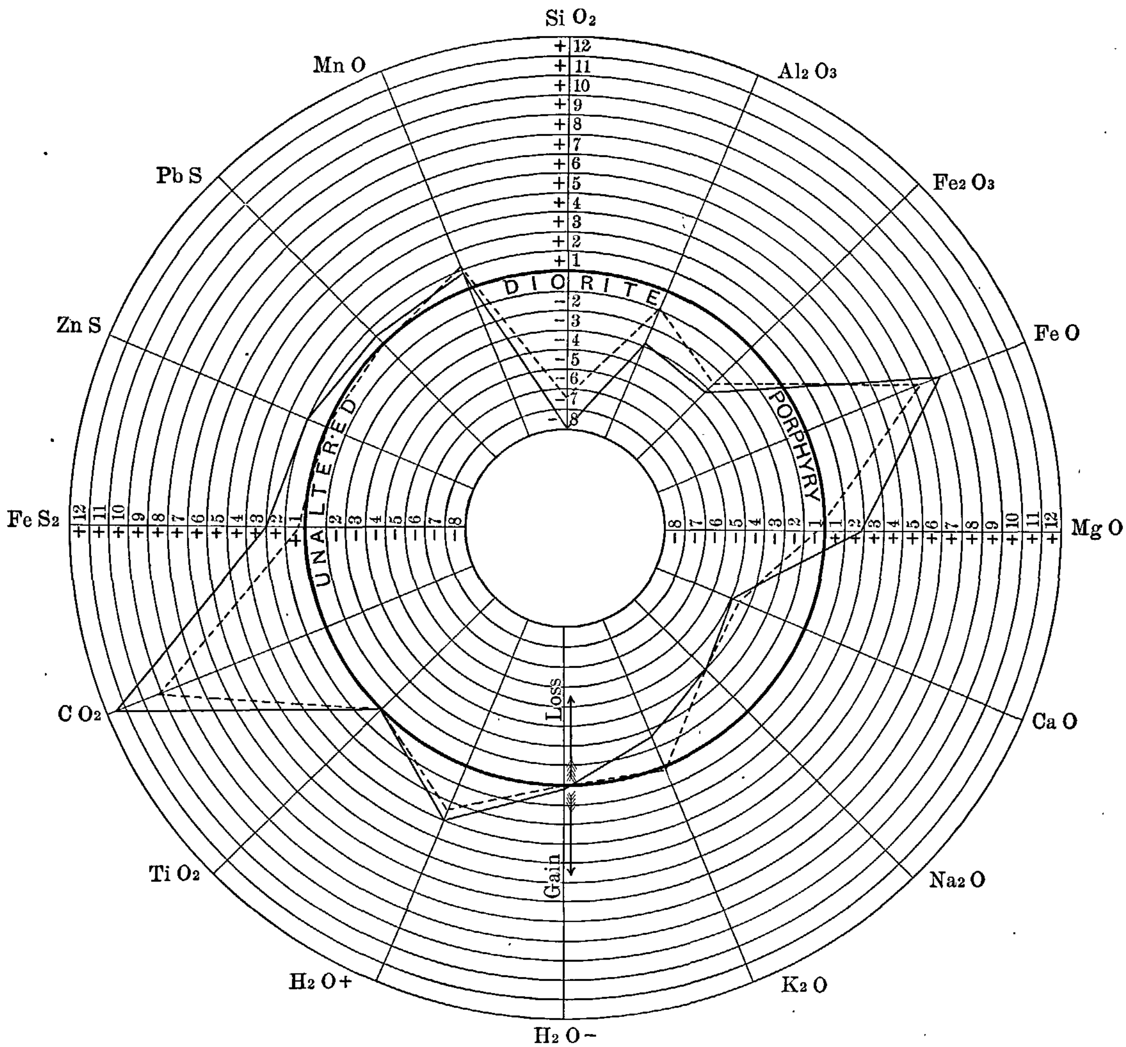


FIGURE 11.—Diagram illustrating gains and losses of each chemical constituent in terms of percentage of mass of original fresh diorite porphyry. Radial distances between successive circles correspond to 1 per cent. Gains are outside and losses inside of the heavy circle representing fresh diorite porphyry. Dash-lined angular outline represents partly altered porphyry. Full-lined outline represents fully altered porphyry. Areas have no significance.

gravities of the respective rock masses will give approximately the weight in grams of each constituent contained in 100 cubic centimeters of each of the three varieties of rock. The results are shown in columns 1a, 2a, and 3a of the table on page 96.

The gains and losses arrived at in columns 6a and 6b may be applied directly by addition or subtraction to the figures of the chemical analysis of the fresh rock, and this, as shown by the following table, perhaps will express the nature of the change more clearly than is done by the larger table.

Table showing the alteration of diorite porphyry in percentage of original rock mass.

	1	2	3		1	2	3
SiO_2	57.35	51.31	49.48	CO_2	0.46	9.67	12.11
Al_2O_3	16.29	15.42	13.44	P_2O_5	.70	.49	.53
Fe_2O_3	3.15	.55	.02	FeS_2	.09	.37	2.10
FeO	4.36	10.78	11.78	ZnS	None.	....	1.02
MgO	2.41	2.09	4.25	PbS	....	....	.55
CaO	5.66	2.05	1.66	MnO	.12	1.13	.97
Na_2O	4.50	1.39	1.45	BaO	.10	.08	....
K_2O	3.39	3.63	1.79	SrO	.05	.01	....
H_2O-	.15	.17	.33				
H_2O+	.70	3.24	3.60		100.55	103.45	106.15
TiO_2	1.07	1.07	1.07				

1. Chemical analysis of fresh diorite porphyry.
2. Composition of same volume of partly altered rock in percentage of original mass.
3. Composition of same volume of completely altered rock in percentage of original mass.

In a comparison of this kind small fluctuations, such as are shown by the phosphoric anhydride, are of doubtful significance and may be due to unavoidable errors in analysis and calculation. The important facts brought out are the notable decrease in silica, alumina, ferric oxide, lime, and alkalies, accompanied by an increase in ferrous iron, magnesia, and water, with the introduction of sulphides of iron, zinc, and lead and of a large quantity of carbon dioxide.

The chemical changes in the rock are graphically displayed in the accompanying diagram (fig. 10), which is similar to that used by Pirsson[1] for illustrating magmatic differentiation. The abscissas here used are, from right to left, the distances from the vein of the rocks analyzed; the ordinates are molecular proportions of the oxides. With the object of condensing the diagram the silica curve is plotted 70 ordinate divisions below its true position. The very great increase in carbon dioxide, water, and ferrous iron and the nearly parallel decrease in silica, lime, and soda are well brought out by the diagram. Titanic oxide, remaining constant, appears as a horizontal line. Both magnesia and manganous oxide show a notable increase on the whole. Ferric oxide decreases inversely as the increase of pyrite. Potash, after increasing slightly, shows a marked decrease.

These changes may also be graphically illustrated by the distortion along radii corresponding to the various oxides of a circle representing fresh diorite porphyry. A diagram of this kind is shown in figure 11. Here the percentage of gain or loss in each oxide is plotted and the diagram is a graphic representation of the relations recorded in the numerical table on this page.

MINERALOGICAL CHANGES.

It would be of interest to compare also the mineralogical compositions of the fresh and altered rock, more particularly to calculate the quantity of each original mineral in a given volume of fresh rock and to compare that composition with the mineral aggregates making up equal volumes of the altered varieties; but the presence in the fresh rock of the complex minerals biotite, hornblende, and diopside, the exact composition of none of which is known, makes this procedure impracticable. By the help of the microscope and the chemical analyses the following approximate mineralogical compositions are obtained for the altered rocks:

Approximate mineralogical composition of altered diorite porphyry.

	1	2		1	2
Sericite	44.8	30.5	Pyrite	0.4	2.0
Quartz	28.4	31.6	Sphalerite	....	1.0
Kaolinite	....	2.8	Galena	....	.5
Carbonate	24.9	29.3			
Rutile	1.0	1.0		100.0	100.0
Apatite	.5	1.3			

1. Altered rock 10 feet from vein. 2. Altered rock close to vein.

These figures are admittedly not of high accuracy. The analysis of the rock farther from the vein contains nearly 3 per cent too little alumina and nearly 0.5 per cent too little carbon dioxide to satisfy the proportions required by the aggregation of minerals given above. If the analysis is correct, this fact indicates the presence of some nonaluminous silicate containing

[1] Pirsson, L. V., Igneous rocks of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 571.

part of the alkalies here calculated as sericite; but no mineral that would account for this discrepancy has been recognized under the microscope. Both analyses show an excess of water over that required for sericite. The carbonate is highly ferruginous with only a small admixture of calcium carbonate. The proportions calculated for the rock close to the vein are as follows:

Carbonates in altered diorite porphyry close to vein.

Siderite ($FeCO_3$)	63.9
Magnesite ($MgCO_3$)	29.6
Rhodochrosite ($MnCO_3$)	5.2
Calcite ($CaCO_3$)	1.3
	100.0

Microscopically the carbonate appears to be a homogeneous mixture of these isomorphous salts. It belongs to no well-defined mineral species but might be classed as a very impure siderite. The carbonate of the less-altered facies has nearly the following composition:

Carbonates in altered diorite porphyry 10 feet from vein.

Siderite	69.3
Magnesite	17.5
Rhodochrosite	7.3
Calcite	5.9
	100.0

This agrees with the observed fact that the carbonate generally associated with the ores is not all identical in character. The titanium is calculated as rutile, because this mineral is known to occur in similarly altered rocks, although it has not been recognized microscopically in those here studied.

CHARACTER OF SOLUTIONS THAT EFFECTED THE ALTERATION.

If the alteration of the diorite porphyry was effected by the continuous action of solutions of one kind and origin it appears that these were rich in bicarbonates of iron, magnesium, manganese, and calcium but poor in silica and alkalies. They carried also sulphur, zinc, and lead with probably free carbonic and sulphydric acids. Notwithstanding the comparatively shallow depth at which the samples studied were collected, they do not suggest the action of water derived directly from the surface. The occurrence of a little kaolinite close to the vein (shown in the calculated composition on p. 99 but not certainly identified under the microscope) may record slight modification by waters from the surface of rock previously altered by ascending vein solutions.

ALTERATION OF THE QUARTZ MONZONITE PORPHYRY (SILICIC TYPE).

GENERAL CHARACTER.

The alteration of the silicic type of monzonite porphyry has not been as fully investigated as that of the diorite porphyry, chiefly because no opportunity was found of studying the change from fresh to altered rock at any considerable depth in any single locality. Alteration is well displayed in the Jessie mine, for example, but the accessible workings are all shallow and metasomatism has modified all of the porphyry exposed in or near the mine so that fresh material for comparison is not locally available. This rock, with its large phenocrysts of feldspar, appears to have been more generally permeable to vein-forming solutions than was the close-grained diorite porphyry of the Wellington mine. Consequently extensive masses of the rock contain abundant disseminated pyrite, sphalerite, and galena. The feldspar phenocrysts were particularly susceptible to attack and the pseudomorphous replacement of these by aggregates of the three sulphides mentioned is generally a characteristic feature of the porphyry in the vicinity of the ore-bearing fissures. The microscope shows that the siliceous porphyry of the Jessie mine is completely altered to an aggregate of quartz, sericite, and sulphides, the original quartz phenocrysts being the only important primary mineral remaining. The former biotite phenocrysts, though retaining their shape, are changed to sericite or muscovite and, like the orthoclase crystals, are in general partly replaced by crystals of pyrite, sphalerite, or galena.

The general outlines of the feldspar phenocrysts are still recognizable, although the pseudomorphic aggregates merge to some extent with the groundmass.

CHEMICAL AND MINERALOGICAL CHANGES.

A chemical analysis of the altered porphyry from the Jessie mine is given in column 3 of the following table, analysis of similar fresh porphyry being placed under 1 and 2 for comparison:

Chemical analyses of fresh and altered quartz monzonite porphyry.

[R. C. Wells, analyst.]

	1	2	3		1	2	3
SiO_2	67.53	68.14	69.61	P_2O_5	0.01	0.17	0.04
Al_2O_3	15.46	15.29	15.12	F	.03	None.	....
Fe_2O_3	2.18	.35	....	NiO	None.	.01	Trace.
FeO	2.42	1.66	[a] .37	MnO	.10	.12	.14
MgO	.16	.26	Trace.	BaO	.07	.03	None.
CaO	3.24	3.03	.05	SrO	None.	.03	None.
Na_2O	3.24	3.59	.42	FeS_2	.09	1.52	6.92
K_2O	3.86	4.07	4.54	ZnS	....	....	.08
H_2O-	.23	.40	.27	PbS	....	....	.06
H_2O+	.55	.39	2.01	CuS	....	....	.17
TiO_2	.41	.36	.36				
ZrO_2	.02	.01	.02		99.63	99.65	100.18
CO_2	.03	.22	None.				

[a] Ferrous iron determination uncertain in presence of sulphides.

1. Brewery Hill. Fresh.
2. Mouth of Browns Gulch. Contains considerable pyrite, but is generally fresh.
3. Jessie mine. Much altered.

As the fresher rocks are not from the same locality as the altered rock, and probably neither was quite identical with the original rock of the Jessie mass, no such detailed comparison has been attempted as was made for the rocks of the Wellington mine. The analyses themselves illustrate in a general way what has taken place. There has been a decided loss in most of the constituents. Silica and alumina have not been greatly changed, and the potash may possibly have been actually increased. Water, sulphur, and heavy metals have certainly been added. The mineralogical composition of the altered porphyry may be calculated as follows:

Approximate mineralogical composition of altered porphyry of the Jessie mine.

	Per cent by weight.
Quartz	52.0
Sericite	40.2
Pyrite	7.1
Sphalerite and galena	.2
Other constituents	.5
	100.0

This same kind of alteration—pronounced sericitization with little or no development of carbonates—is found also at the I. X. L. mine, and appears to be generally a characteristic accompaniment of these deposits in the siliceous monzonite porphyry. Not only has no carbon dioxide been added to this rock, but the alkaline earths originally present have been virtually all removed. Within the region of ore deposition the contents of the ore-bearing solutions appear to have been notably different in the two types of porphyry, for the observed divergence in effects could not be accounted for wholly by differences in the composition of the rocks on the assumption that the solutions were identical at the places where the ores were precipitated. On the other hand, the solutions do not appear to have been radically or originally different. Their contents in certain constituent bases appear to be significantly related to the compositions of the two porphyries.

Near the surface the rock that is altered in the manner just described has its sericite partly or wholly changed to kaolinite.

PROPYLITIZATION.

The propylitic type of metamorphism is to some extent illustrated by nearly all of the monzonite porphyry. In every specimen of that rock collected from surface exposures the biotite shows the characteristic alteration to lenses of chlorite, with interlamellar grains or plates of calcite or epidote or both. This pseudomorphous change is illustrated in Plate X, *A* and *B* (p. 54). The pyroxene and hornblende have generally been transformed partly or wholly to aggregates of these same secondary minerals, and the feldspars as a rule contain some calcite, sericite, and kaolinite. There is generally, too, more or less development of quartz and pyrite at the expense of the original minerals of the rock, although the sulphide is not normally abundant. The carbonate, called calcite for convenience, is probably not all pure calcium carbonate, but has on the whole the habit and optical character of calcite rather than of the ferruginous and magnesic carbonate described on page 100 as formed by the alteration of wall rock.

The facts available in the Breckenridge district indicate that this propylitic alteration is restricted to rocks within 300 feet of the surface. It is characteristic, for example, of all known surface exposures on Mineral Hill, while long tunnels into the same hill, such as those of the Wellington and Rose of Breckenridge mines, reveal nearly fresh material. The rock cited on page 95 for comparison with altered wall rock is not propylitically altered; neither does that kind of alteration appear to be a significant accompaniment of the veins or to intervene between fresh rock and the carbonated rock of the vein walls. Finally, the propylitic alteration does not, in this district, appear to be any more characteristic of those areas or rock masses containing ore deposits than of others in which ore-bearing solutions have apparently not been active.

Much of the quartz monzonite porphyry has also been propylitically altered, but as it contains a smaller proportion of femic constituents the change is not so conspicuous as in the more calcic porphyries.

That propylitic metamorphism of andesitic or dioritic rocks is a very characteristic accompaniment of ore deposition in many mining regions is of course well known, and there can be little question that the alteration in some of those regions has been effected through the widespread penetration of the rocks by carbonate solutions, or by solutions carrying carbon dioxide and hydrogen sulphide, that have worked outward from the ore-bearing fissures. Propylitization is undoubtedly in most cases a form of hydrothermal metamorphism, yet, as Rosenbusch [1] remarks, it is not to be denied that ordinary weathering might produce similar results. The chief agent in the change appears to be carbon dioxide in solution, and it is reasonable to suppose that the work of dilute carbonate solutions representing the weaker and cooler phases of hydrothermal action may be closely imitated by that of similar solutions percolating downward from the superficial zone of oxidation and disintegration. In other words, although it is perhaps objectionable to speak of propylitic alteration without qualification as weathering, the change may nevertheless be due to the deeper action, for the most part below water level, of solutions derived from the zone of ordinary superficial weathering. Some such explanation appears to be necessary to account for the facts observable at Breckenridge. It is possible that the very common association of propylitization with ore deposits may in part be assignable not so much to the direct action of the original ore-bearing solutions as to a difference in the vadose solutions later produced by weathering in metallized as contrasted with unmetallized districts. In metallized districts the presence of sulphides in the disintegrating and oxidizing rocks gives rise to solutions containing one or more of the sulphur acids and these not only increase the chemical activity of the vadose waters but provide them with sulphur for the formation of pyrite in the deeper zones at the expense of the magnetite and iron-bearing silicates in the fresh rock. This view, while connecting propylitic metamorphism in a secondary or remote way with hydrothermal activity, does not require the same close relationship between the veins and the propylitically altered rocks as the view postulating contemporaneity of ore deposition and propylitization. Where, in connection with the development of chlorite, calcite, and epidote, pyrite also is abundantly formed or introduced there would seem to be good reason, in the absence of opposing evidence, for regarding the alteration as hydrothermal; but where, as at Breckenridge, the modified rock is not conspicuously and generally pyritized the way appears to be open to an explanation involving the action of solutions working downward from the surface. This second hypothesis best fits the facts in the Breckenridge district, so far as they can be determined with the present unsatisfactory opportunities for underground study.

[1] Rosenbusch, H., Mikroscopische Physiographie der massigen Gesteine, Stuttgart, 1908, p. 1105.

CHAPTER VIII.

THE PRIMARY ORE DEPOSITS IN GENERAL.

MINING.

GENERAL STATE OF ACTIVITY AND DEVELOPMENT.

As it will be necessary in this and in succeeding chapters to refer frequently to the several mines, a general preliminary account of them with particular reference to development and situation may appropriately be given in advance.

In 1909 four mines only were shipping at all steadily. These were the Wellington, Country Boy, and Sallie Barber, in French Gulch, and the Laurium, or Blue Flag, in Illinois Gulch. Of these only two, the Wellington and Country Boy, can be said to have maintained an important production. The Hamilton and Puzzle mines were being reopened, it is true, and in a few other places two or three men—as a rule lessees—were at work taking out a little ore or prospecting. Outside of the area thoroughly studied the Arctic and Ling mines, near the head of the Blue, were being operated in a small way. On the whole, therefore, deep mining in this district is undeniably at a low ebb.

In the early days of mining shafts were more popular than they later became and many of such openings sunk on the hilltops were afterward undercut by tunnels. A few shafts, among which may be mentioned the Oro, in French Gulch, and the Mountain Pride, in Illinois Gulch, were continued below water level, in situations where tunneling was not practicable; but these were finally abandoned. The depth of most of the old water-filled shafts is not now readily ascertained. The so-called Finding deep shaft, on Shock Hill, is more than 300 feet deep, but how much deeper could not be learned. The Ouray, Oro, Sallie Barber, and Little Sallie Barber shafts are all between 300 and 400 feet deep and it is doubtful whether there is a 500-foot shaft within the area mapped, although just outside of that area are the Wonderful London, near Hoosier Pass, 570 feet deep, and the Warrior's Mark shaft, near Boreas, reported to be 700 feet deep. The Wellington and Country Boy are worked by means of adits, and this was the mode of development used in most of the mines productive in the past. A few long tunnels, notably the Lightburn, reported to be over 2,000 feet in length, and the French Creek, about 2,100 feet long, have been driven as prospecting ventures.

REVIEW OF THE NORTHERN AND CENTRAL PARTS OF THE AREA.

UP FRENCH GULCH AND OVER FARNCOMB HILL.

A newcomer to Breckenridge may perhaps be so fortunate as to be conducted over the district by some one able to point out the different mines and pleased to tell their stories to an interested listener. By a little exercise of the imagination and the aid of the accompanying maps and illustrations the reader may, if he chooses, pursue a similar itinerary in shorter time, although with less enjoyment than if the scenes passed in reality before his eyes.

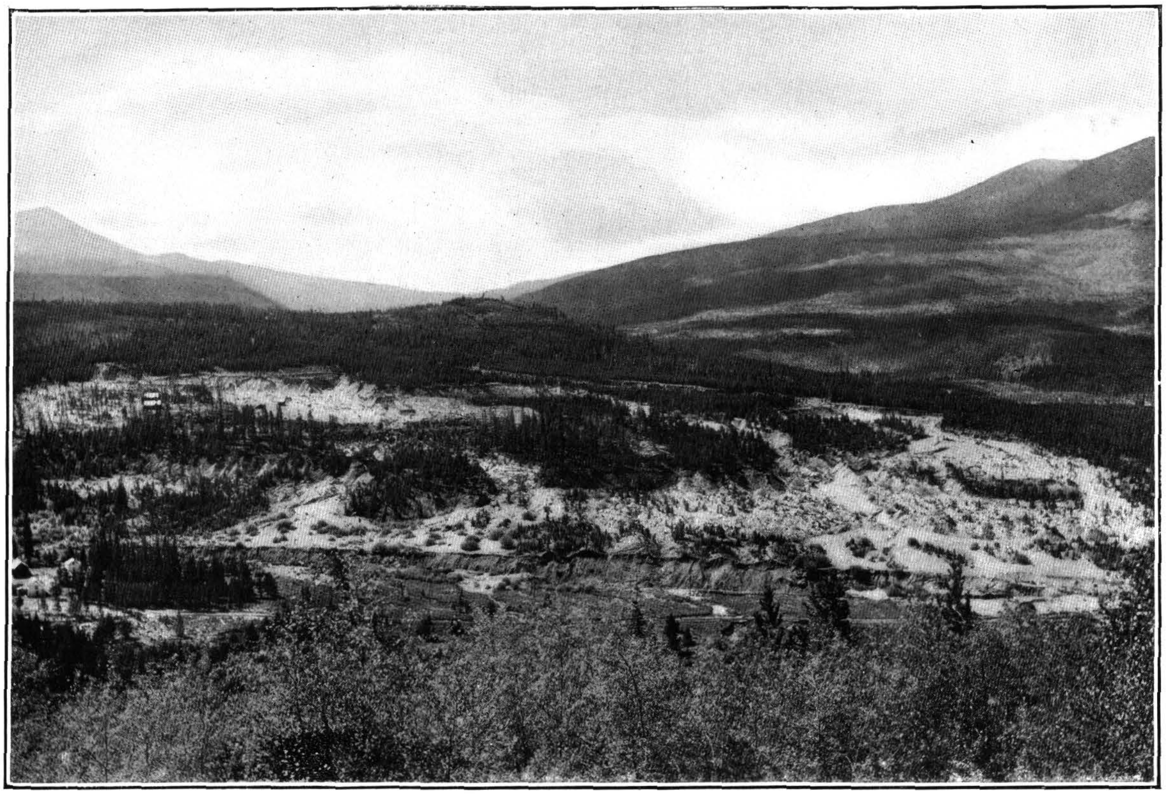
From Breckenridge a road (see Pl. I, in pocket) leads northeast over a low wooded spur of terrace gravels into French Gulch, where attention is likely to be drawn, first, to the old hydraulic workings of the Mekka placer on the right of the road. A general view of these workings is given in Plate XXIII, *A*. To the north, on Gibson Hill, appear the dumps of the Alice A., Bullion King, and other tunnels driven to exploit the blankets or so-called contacts in the Dakota beds. At the base of the hill, near Gibson Gulch, are the New York tunnel and the Johannesburg tunnel. At the mouth of the latter, which connects with a shaft about 350 feet higher up the hill, is a small mill. About a third of a mile farther up French Creek, on the left, is the Old Union mill, equipped with rolls, half a dozen Harz jigs, and 10 Wilfley tables. From this a tunnel about 1,600 feet long has been driven in a northeast direction into Prospect Hill and connects with two shafts whose collars are about 350 feet higher on the spur east of Prospect Gulch. (See Pl. XXIV, *B*.) On the south side of the creek, partly concealed among the trees on Nigger Hill, may be seen the shaft houses of the Dunkin and Juniata mines, just west of Nigger Gulch. The Juniata was formerly productive and at one time a bitter legal fight was waged between the two rival companies for the ownership of the Juniata vein. These shafts are now abandoned, although in 1909 lessees were working in some tunnels on the southern part of the Dunkin ground, on the south slope of Nigger Hill.

Thus far up French Gulch there has been no sign of recent lode-mining activity, although at the bend in the creek near the Old Union mill the Reliance and Reiling dredges are busily engaged in turning over the deep auriferous gravels, as shown in Plate XXIV, *B*. A short distance above the locality where the dredges are at work the Oro workings of the Wellington mine come into view on the left of the road (Pl. XXVII, *A*, p. 128). The main adit enters the hill near the mill and the underground workings extend northeastward under Mineral Hill for about half a mile and connect with another adit known as the Extenuate (or, as usually written, X. 10. U. 8) tunnel, which is about 2,000 feet farther up French Gulch and 100 feet higher than the adit by the mill. The disused Oro shaft is just east of the mill. In 1909 the Wellington was shipping from 30 to 35 tons of galena and sphalerite concentrates a day. Virtually all work is confined to the Oro and Extenuate levels. On the side of Mineral Hill, above these main adits, may be seen the dumps of the Siam, Orthodox, Liberty. Wellington. and other old tunnels of the group, ingress to all of which is now blocked.

On the south side of the creek, nearly opposite the Wellington mine, is the Country Boy, which in 1909, after a period of idleness, was shipping zinc ore. Here there is a lower adit, about 50 feet above the creek and 1,100 feet long, and an upper adit, 1,700 feet long, nearly 200 feet above the lower one. About 1,500 feet east of the Country Boy, on the same side of the gulch, is the Helen tunnel, which in 1908 was being run to cut the supposed northeasterly continuation of the Country Boy vein. It had been abandoned in 1909 and the face could no longer be reached. Above it on the spur just west of Australia Gulch are the older workings on the same group of claims. High on the spur east of Australia Gulch and scarcely visible from French Gulch on account of the trees (see Pl. V, *B*, p. 20) are the shafts of the Sallie Barber and Little Sallie Barber mines, the former 365 and the latter 300 feet deep. These are small producers of zinc ore and the workings of neither mine are extensive. Nearly 400 feet below them in French Gulch is the French Creek tunnel, 2,100 feet long, driven without success nearly due south under Bald Mountain.

On the north side of the gulch the precipitous slope of Mineral Hill is pierced by a number of abandoned adits driven to cut the north-northeast veins of the Wellington zone. The lower and longer tunnels are those of the Rose of Breckenridge, Minnie, and Lucky mines, the last two being supplied with small mills. The Lucky adit was formerly known as the Mineral Hill tunnel. Above these are older tunnels, including the Cincinnati, once a producer of high-grade lead ore. Finally, on top of the hill are many old shafts long since allowed to fall into decay. The Minnie and Lucky were both productive and the latter was in 1887 the chief lead-silver mine in the district.

Leaving Mineral Hill, the road passes through Lincoln, once an active milling and placer-mining center but now almost deserted, and begins the ascent of Humbug and Farncomb hills. On the left, near the foot of the grade, is a tunnel from which issues a strong stream of ferruginous water. This is the McLeod tunnel, which runs north for about 1,000 feet to connect with the Juventa shaft, on the west slope of Humbug Hill. This shaft produced some ore in 1889, but, like most of the others in the district, is now abandoned. As the road nears the crest it affords a view down French Gulch (Pl. V, *B*, p. 20) and to the southeast, where Mount Guyot, a mass



A. TERRACE GRAVELS (MEKKA PLACER) ON SOUTH SIDE OF FRENCH GULCH AS SEEN FROM GIBSON HILL.

In the distance is Hoosier Pass, on the right of which is seen the even east slope of the Tenmile Range. To the left of the pass is Red Peak, composed of the ruddy beds of the Maroon and "Wyoming" formations with some sheets of porphyry, all dipping to the east. The wooded slopes of Nigger Hill occupy the middle ground. The natural channel of French Creek is hidden by the aspens in the foreground, the deep trench visible being an artificial sluice from placers to the left. See page 72.

B. BRECKENRIDGE AND THE TENMILE RANGE FROM LITTLE MOUNTAIN.

The view is northwest. Directly behind the town is Shock Hill, and along the west side of the Blue may be seen the light scars of hydraulic workings in the terrace gravels The low, rounded hill in the distance, just to the left of the tree, is of Dakota quartzite lapping up on the pre-Cambrian west of Braddocks.

of porphyry overlying shale, rises boldly above the timbered slopes of upper French and Little French gulches. Almost directly underfoot, so steep is the slope, are the buildings and tunnels of the Wire Patch mine, on the south side of Farncomb Hill, and almost on a level with the road and a little southeast of it is the open stope in the Elephant ore body, now part of the Wire Patch, which yielded largely in the eighties. Directly in the saddle through which the road passes is the Ontario shaft, where gold was first found in place 30 years ago. This is probably not more than 150 feet deep. The Ontario ground is opened also by tunnels from both sides of the ridge, all abandoned and in poor condition.

Before the descent of the north slope of Farncomb Hill is begun a few moments may be spared for the fine prospect spread out to the northeast. Near at hand may be seen the dark shale beds of American and Georgia gulches, from which the loose material has been washed by the old placer miners. Beyond them is the well-timbered upper valley of the Swan. The view up the middle fork of that river is nearly the same as the one shown in Plate XVII, *B* (p. 76), with the crest of the Continental Divide in the distance. Twelve miles to the northeast may be seen the lofty pointed summits of Grays and Torreys peaks, which dominate the rugged country about Montezuma and Argentine.

The road down the hill to the Swan passes over steep slopes of dark shale encumbered by countless small dumps, and perforated by many tunnels, most of them small and all grouped with little apparent system. (See Pl. XXVII, *B*, p. 128.) The numerous small gold-bearing veins trend generally northwest and have no real outcrops. Many of the tunnels have been run by lessees. Some are crosscuts and some follow the veins. Some are short and simple; others crosscut from vein to vein and connect with extensive and labyrinthine workings with numerous levels at short intervals connected by raises. Many can no longer be entered and some of the most extensive are covered at the portals with waste from subsequent excavations. The road to American Gulch crosses the Key West, Boss, and Reveille veins and a branch, skirting the hill to the Fountain vein, passes over the Carpenter, Black, Gold Flake, Wheeler, Graton, Silver, and Bondholder veins of the Wapiti group. A few lessees, perhaps half a dozen men, were at work on these veins in 1909. Just above the point where the road turns into American Gulch is the portal of the Fair tunnel of the Wapiti Mining Co. This runs southwestward for about 1,000 feet but cuts the veins below the level at which they were productive. Raises, however, connect the Fair tunnel with workings above it.

DOWN THE SWAN AND BACK TO BRECKENRIDGE BY WAY OF GOLD RUN AND GIBSON HILL.

The road now continues down American Gulch to the Swan, past the mouth of Georgia Gulch, where a few timbers projecting from placer débris mark the site where once stood the placer town of Parkville; past Snider's camp, where an attempt is being made to work the deep gravels; and into the broader valley of the main river near the abandoned settlement of Swan City. Just before Swan City is reached attention is attracted by the ruined mill of the I. X. L. mine on the south side of the valley. This mine, developed by tunnels, produced in a small way for many years. Half a mile south of Swan City, on the east side of Browns Gulch, is the Cashier mine, having adits on three levels and some very large stopes in porphyry. For a number of years this yielded a low-grade gold-silver ore which was treated in a 40-stamp mill, now removed.

A mile west of Swan City is Summit Gulch, with the Hamilton mine near its head, a mile from the Swan. This mine was worked in a primitive way for many years and then lay idle for a decade, until 1909, when it passed into new hands. Large stopes have been opened in metalized fissure zones in porphyry and the mine is credited with an output of about $400,000. Most of the ore, which was valuable chiefly for gold and silver, was concentrated in a little 10-stamp mill.

There are no more mines of consequence along the Swan, and unless the traveler wishes to visit the dredges near Valdoro he may advantageously turn his route across Delaware Flats and up through the placers of Gold Run, shown in Plate XVI, *A* (p. 74). Near the upper end of these placers, on the northeast side of the run, is the Jessie mine, of which a general view is given in Plate XXIX, *A* (p. 144). This mine has been a fairly large producer of low-grade gold-silver ore similar in its occurrence to that of the Cashier and Hamilton mines. The mine is extensively developed by four adits, of which parts of two only, the Glenwood and Jessie, are now open. These are approximately on the same level and connect. The ore mined probably averaged from $3 to $6 a ton, and the total production is variously reported at $800,000 to $1,500,000. There is a 40-stamp mill at the mine.

Leaving the Jessie, the road ascends the north slope of Gibson Hill and passes successively the Extension, Jumbo, and Little Corporal mines, all abandoned and inaccessible. The Jumbo produced considerable gold ore from the oxidized portion of a vein in monzonite porphyry and quartzite, most of which was milled at the mouth of Cucumber Gulch. The Extension company worked what is supposed to be the same vein and milled the ore in a 20-stamp mill at the mine. Both mines were opened by adits and did not attain great depth. Of the Little Corporal, worked through a shaft in quartzite, no details could be ascertained.

Crossing over the crest of Gibson Hill through the pass near the Little Corporal, the road skirts the west side of the hill and affords a broad outlook over the valley of the Blue. (See Pl. XIV, *B*, p. 70.) Below the road, along the west base of the hill, are the Sultana, Fox Lake, and other tunnels on two or more pyritized beds in the strip of "Wyoming" formation exposed along the Blue. The two named have produced some ore—how much is not known, although the Sultana shipped both carbonate and sulphide ore with considerable regularity from 1888 to 1898. Higher up the hill, near the road, are the Eureka shaft and the Kellogg and Alice A. tunnels, all exploiting flat-lying metallized beds in the Dakota formation. The Kellogg is credited with a considerable production and was one of the well-known mines in the early eighties; but little reliable information can be obtained regarding the workings and the character of these deposits can be learned imperfectly only through hearsay. Across the Blue, in Shock Hill, may be seen the Iron Mask mine (Pl. XIV, *B*, p. 70), which was for many years a producer of rich lead-silver ore from "contacts" above and below a sheet of porphyry, shipping for a time at the rate of two or three cars a week. It was worked through an 1,800-foot adit. The total output is said to have been about $50,000. On the top of Shock Hill is the Finding shaft, recording an apparently ill-advised attempt, dating from about 1898, to find ore bodies resembling those of Leadville. On the west side of the hill, not visible from Gibson Hill, are the Brooks-Snider workings and dismantled 20-stamp mill. The material milled apparently was fractured quartzite carrying native gold. There is no vein in sight and the operations were certainly not profitable. From the Alice A. the road, from which was taken the view shown in Plate IV, *B* (p. 18), descends to Prospect Gulch and French Creek.

REVIEW OF THE SOUTHERN MINES.

ILLINOIS GULCH.

A second and shorter excursion will suffice to review the mines in the vicinity of Illinois Gulch, the road to which passes southward out of Breckenridge past the abandoned placer pit of the Gold Pan Co. On the south side of Illinois Gulch near its mouth is Little Mountain, a hill of gently dipping Dakota quartzite. In the fractures of this rock have been found some bunches of rich oxidized gold-silver ore. In all, ore to the value of probably $40,000 to $50,000 has been taken from this hill, mostly between 1898 and 1900; one small pocket alone, close to the surface above the Germania tunnel, yielded $30,000. Just east of Little Mountain is the portal of the Willard tunnel of the Puzzle mine. This adit, after following the Puzzle-Ouray vein through the hill to the Puzzle-Extension shaft in Illinois Gulch, just above the mouth of Dry Gulch, crosscuts north 300 feet to the nearly parallel Gold Dust vein. The Ouray workings adjoin those of the Puzzle on the southwest. From 1885 to 1897 these three closely connected mines produced much rich silver-lead ore carrying considerable gold; but the Puzzle and Ouray Cos., owning intersecting claims on the same vein, were for much of this time engaged in litigation. After long idleness the Willard tunnel was cleaned out in 1909, some ore was milled from the Gold Dust vein, and preparations were made to prospect the vein at depth. On the south slope of Nigger Hill, north of the Puzzle and Gold Dust workings, are a number of tunnels on the ground of the Dunkin Mining Co., where three veins are recognized, all trending northeast. From northwest to southeast these are the Juniata, Dunkin, and Maxwell veins. Ore amounting in value to over $65,000 is said to have been taken by lessees from the Gallagher tunnel on the Dunkin vein. The total production from all workings was probably much greater.

About 1,000 feet farther up Illinois Gulch than the Puzzle Extension shaft is the main adit of the Washington mine. The Washington vein, said to be accompanied by two others nearly parallel, the Emmet and Atlantic veins, strikes northeastward over the spur connecting Bald Mountain and Nigger Hill. There are a number of tunnels on the different veins, but none could be entered in 1909. The mine is an old one and was first worked through a shaft on top of the ridge. It is said to have produced from $400,000 to $500,000, partly from shipping ore and partly from material treated in a 20-stamp mill.

In the upper part of Illinois Gulch, where it widens out into the slopes of Bald Mountain, is the Laurium mine, in pre-Cambrian rocks, recently opened by the Blue Flag Mining Co. after a long period of idleness. This, one of the first mines worked in the district, originally produced lead ore, but now has a 60-ton mill and yields a pyritic concentrate carrying gold and silver. It is opened by an adit and attains no great depth. It is credited with a production of about $80,000. A little farther up the gulch, in the "Wyoming" beds, is the Mountain Pride mine. This was developed by two shafts 500 feet apart and apparently from 250 to 300 feet deep. Work on this mine appears to have begun about 1888; some carbonate ore was shipped in 1896; and in 1898 the Mountain Pride led the district in production. At this time a diamond-drill hole was started with the intention of going 1,000 feet. It evidently entered the pre-Cambrian far short of that depth, but all efforts to obtain data regarding this drill hole, reported to be 1,100 feet deep, have been futile. The mine and a mill equipped with two sets of rolls, two 3-compartment jigs, and five Wilfley tables have been abandoned to ruin.

Northeast of the Mountain Pride mine are the Golden Edge and the Gold Bell mines, on fissures in the Dakota quartzite, which extends under the porphyry of Bald Mountain. The Golden Edge is abandoned, but the Gold Bell is a new prospect in which a little ore was visible in 1909. High on the slope above the Golden Edge is the Carbonate, a small mine in the porphyry with a record of a few shipments of excellent lead carbonate ore a few years ago. It is now idle.

VALLEY OF THE BLUE SOUTH OF BRECKENRIDGE.

There are still a few other mines which, although outside of the area mapped, are, broadly speaking, in the Breckenridge district and deserve mention here.

About 7 miles up the Blue from Breckenridge is the Governor mine, in beds apparently belonging to the "Weber formation." This was formerly productive, but has been idle for many years and can not now be entered. It was worked through adits and the ore was treated in a small mill. Near the head of the Blue, at the base of Quandary Mountain, is the Monte Cristo mine, which was briefly described by Emmons[1] many years ago. The ore, consisting of metallized Paleozoic limestone, was quarried and concentrated. The mine has long been idle. A little farther up the Blue are the Senator, Arctic, and Ling mines, all working through tunnels in a small way on gold-bearing veins in the pre-Cambrian.

CONCLUSION.

This completes the general survey of lode-mining activity in the Breckenridge district. With the possible exception of the Wellington there is not a mine among all those mentioned that is systematically and extensively developed and that can be regarded as steadily and

[1] Mon. U. S. Geol. Survey, vol. 12, 1886, p. 520.

profitably productive. By far the greater number are abandoned, with not even a watchman in charge. Detailed and accurate mine maps are as a rule unobtainable. Even the Wellington Mines Co. keeps neither stope maps nor sections and has very imperfect records of its old workings. The maps of many of the abandoned mines have been carried out of the district and are stored away with old books and papers in different parts of the country. As ingress to the workings themselves is generally impracticable the data available for a study of the ore deposits are exceptionally meager, in spite of the hearty willingness of most of the men now in the district to further such an investigation.

TENOR AND TREATMENT OF THE ORES.

The Breckenridge district has yielded ores of widely varied kinds and richness, ranging from the masses of native gold from Farncomb Hill, on the one hand, to the zinc ores of French Gulch or to the concentrating ore of the Jessie mine, on the other.

The average value of the shipping ore and concentrates, exclusive of course of the Farncomb Hill pockets, may be roundly estimated at $25 a ton, gross. Some idea of the character of the ores and concentrates shipped from the district in the past may be had from the following table. Some of the compositions given are actual sampler analyses chosen as fairly representative of the ore from a certain deposit; others are generalized averages of a number of analyses.

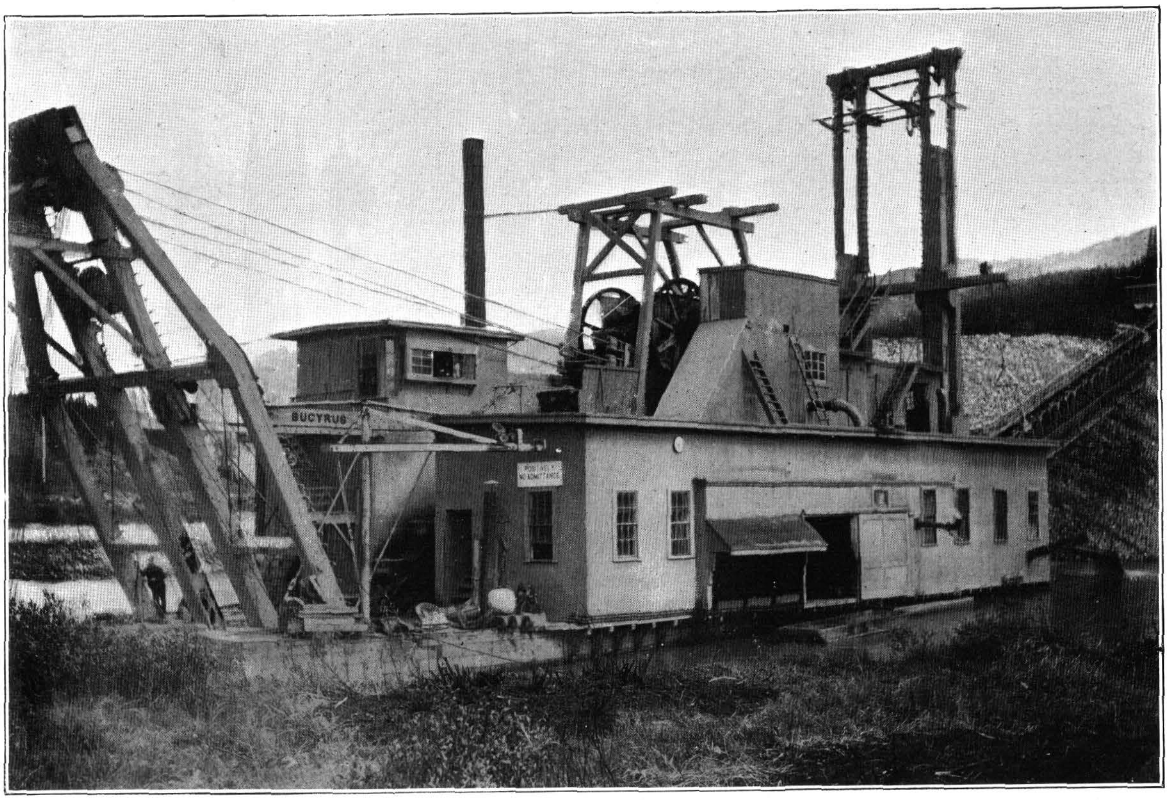
Composition of Breckenridge ores.

	Wellington.			Country Boy.	Puzzle.	Gold ust	Cincinnati.	Minnie.	Truax.
Kind of material [a]	C	S	[b] S	S	S	S	[c] C	C	[d] S
Gold, ounces per ton	0.02	0.02	0.10		0.07	0.25	0.01	0.03	0.06
Silver, do	10.00	10.00	25.00		24.00	20.00	10.50	16.00	17.00
Lead, per cent	50	45	45		[e] 25	55	43.5	67	20
Zinc, do	5	6		43	8	6			
Iron, do	14	10	6		14	4	10	7	
Silica, do	5	7	12		24	7	12	3	42
Date	1909	1909	1909	1909			1901		

	Old Union.	Dunkin.	Washington.	Iron Mask.	Brooks-Snider.	Mountain Pride.		Kellogg.	Jumbo.
Kind of material [a]	S	S	[f] S	[g] S	C(?)	S	C	[h] S	C
Gold, ounces per ton	0.07	0.60	0.60	0.03	1.3	0.3	1.2	0.06	0.46
Silver, do	8.00	15.00	26.40	21.00	3.0	9.0	8.5	20.00	1.90
Lead, per cent	31	40	39	58		50	30	59	
Zinc, do						7	12		
Iron, do	12	8	7	3	3	9	15	4	35
Silica, do	29	32	25	9	71	5.5	6	9	16
Date	1902			1901	1898	1902		1899	

	Cashier.	Wire Patch.	Jessie.	Hamilton.	Germania.		Carbonate (Bald Mountain).	Etigrade (Little Mountain).	Boss.
Kind of material [a]	[g] S	C	C	S	S	S	[h] S	[g] S	[i] S
Gold, ounces per ton	0.55	0.90	1.07	0.67	0.12	0.17	0.4	0.20-1.65	36
Silver, do	10.00	10.00	11.89	4.15	70.00	152.61	25.0	500-726	27
Lead, per cent			6		([j])	8.7	40	4-13	
Zinc, do	5		13						
Iron, do	40	34	30	39		3	12	9	
Silica, do	5	10	5	6	80	78	5	66	
Date	1904	1908	1897	1903					1909

[a] S, Shipping ore; C, concentrates.
[b] Carbonate ore from surface workings; 1.5 per cent of sulphur.
[c] 5 per cent of sulphur.
[d] Partly oxidized.
[e] Below average.
[f] Horn tunnel; 5 per cent of su phur.
[g] Oxidized ore.
[h] Oxidized ore; 1.5 per cent of sulphur.
[i] Tailings from a rich pocket.
[j] Otherwise similar ore carries up to 30 per cent of lead.



A. DREDGE ON THE BLUE, NEAR THE MOUTH OF THE SWAN.

In 1909 this boat was working in difficult ground with many huge bowlders. It was not put into commission in 1910. It has $9\frac{1}{2}$ foot open-connected buckets. See page 180.

B. VIEW UP FRENCH GULCH FROM NIGGER HILL, SHOWING MINES AND DREDGING OPERATIONS.

1. Reiling dredge. This has just turned after a successful run upstream. 2. Reliance dredge. 3. Wellington mine (Oro workings). 4. Old Union shafts. 5. Old Union mill and tunnel. 6. Country Boy mine. 7. Mineral Hill. 8. Farncomb Hill. 9. Minnie tunnel (among trees). 10. Lucky tunnel. 11. Lincoln. See page 180.

Milling has been practiced in the district from an early period in its history. One of the first mills was built at Lincoln to treat ore from the Old Reliable vein and was run by water power. Another early mill was the 20-stamp Brooks-Snider, on Shock Hill, erected in 1881, but never thoroughly successful. In January, 1886, the local milling facilities were as follows:

Eureka mill, Cucumber Gulch	30 stamps.
Washington mill, Bald Mountain	20 stamps.
Brooks-Snider mill, Shock Hill	20 stamps.
Lincoln mill, Lincoln	15 stamps.
Wheeler mill, Lincoln	10 stamps.
Blanchard mill, Lincoln	5 stamps.
Ryan & Hartman mill, Lincoln	Huntingtons.
Russell & Nashold mill, Breckenridge	Wiswell pulverizers.

At this time also a 10-stamp mill was under construction where the present Jessie mill stands and there was a mill at the Laurium mine, then idle.

In 1909 the only mills in fairly steady operation were the Wellington mill, equipped with rolls, jigs, and tables, and having a capacity of about 100 tons a day, and the Laurium 60-ton mill, with pulverizers and tables. For a part of the year the old Ware mill, west of Breckenridge, originally built in 1889 to treat ore from Farncomb Hill, was run on ore from the Gold Dust vein, and the old 10-stamp mill at the Hamilton mine was started late in the summer. Small mills were being prepared for work also at the Gold Bell mine, on Bald Mountain, and at the Arctic mine, up the Blue. Standing idle, in various stages of dilapidation, but none quite in ruins, were the Wire Patch concentrating mill, which was in operation in 1908; the Old Union mill, with rolls, jigs, and 10 concentrating tables; the Extension 20-stamp mill; the Jessie 40-stamp mill; the Washington 20-stamp mill; and half a dozen smaller ones. The Cashier 40-stamp mill has been wholly dismantled.

Various attempts at smelting in the district were made prior to 1890, but of course were unsuccessful. The brick stack of the Wilson smelter, built in 1880 and afterwards converted into the Breckenridge 20-stamp mill, marks the site of one of these enterprises just north of town. The mill has long since disappeared.

The marketing of ores and concentrates was facilitated by the sampler built at Breckenridge in 1897 by the Kilton Gold Reduction Co. These works subsequently passed into the hands of the Chamberlain-Dillingham Ore Co., which is closely connected with the American Smelting & Refining Co.

The freight rates on ores from Breckenridge to Colorado smelters ranged in 1909 from $1.50 to $3 a ton on ores up to $18 a ton in assay value, with no increase on higher grade ores.

On crude sulphide lead ores the treatment charges by the smelters range through a sliding scale from $6.50 a ton for 5 per cent ore to 50 cents a ton for 40 per cent ore. No smelting charge is made for sulphide ore carrying over 40 per cent of lead. The prices paid per unit of lead[1] range similarly from 30 cents on 5 per cent ore to 42 cents for 40 per cent ore. For higher-grade ores the price ranges from 42 to 46 cents. These prices are on a so-called neutral basis (that is, an assumed quotation) of $4 a hundredweight for lead. They are increased or diminished by 1 cent for every 5 cents by which the quotation used as a basis for settlement exceeds or falls short, respectively, of the neutral basis. This quotation is not the actual New York quotation, but is 90 per cent of that figure, provided the latter is not over $4. When the New York sales price exceeds $4 the smelter-settlement quotation is $3.60 plus one-half of the excess. Thus the New York sales price will have to be $4.80 in order that the shipper shall receive for his lead the actual price per unit on the $4 basis as given in the smelter schedule. Excess of zinc over 10 per cent is penalized at 50 cents a unit and excesses of iron and silica at 10 cents a unit. Gold, when under 3 ounces a ton, is paid for at $19 an ounce; when over 3 ounces, at $19.50 an ounce. Silver is settled for at 95 per cent of the current New York quotation.

[1] The "unit" is 1 per cent of lead per ton of ore, or 20 pounds.

On lead concentrates carrying from 5 to 30 per cent of lead the treatment charges range from $3.75 to $2.25 a ton. Concentrates with over 30 per cent of lead take the sulphide-ore schedule. The zinc limit in concentrates is 5 per cent, with 30 cents a unit penalty for excess.

Carbonate lead ores are subject to the following schedule:

Prices paid and treatment charges for carbonate lead ores.

Lead contents.	Price per unit (cents).	Treatment charge per ton.	Maximum treatment charge per ton.
	$4 basis.		
Under 5 per cent	0	$5.00	$9.00
From 5 to 10 per cent, inclusive	35	4.50	8.00
Over 10 to 15 per cent, inclusive	38	3.00	7.00
Over 15 to 20 per cent, inclusive	40	2.00	6.00
Over 20 to 25 per cent, inclusive	42	1.00	4.50
Over 25 to 30 per cent, inclusive	44	.00	3.00
	$4.50 basis.		
Over 30 to 35 per cent, inclusive	46	.00	1.50
Over 35 to 40 per cent, inclusive	48	.00	.50
Over 40 to 45 per cent, inclusive	50	.00	.00
Over 45 to 50 per cent, inclusive	51	.00	.00
Over 50 per cent	52	.00	.00

On these ores 25 cents a unit is charged for sulphur in excess of 3 per cent up to the maximum of the sulphide-ore schedule. The zinc limit is 8 per cent, with a penalty of 50 cents a unit for excess.

For siliceous ores containing over 65 per cent of insoluble silica and ranging from $14 to $100 a ton in assay value the charges are from $5 to $13 a ton. When the silica is under 65 per cent and the gross value under $50 a ton, the working charges are from $6 to $10 a ton. In this group the richer the ore the higher the treatment charge.

The zinc ores of the district do not pass through the local sampler. Ores and concentrates containing over 30 per cent of zinc and generally less than 10 per cent of iron go to the smelters of Missouri and Kansas. The zinc in the ore, less 8 units, is commonly paid for by these smelters at the current St. Louis price for spelter less from $14 to $15 a ton of ore, according to its quality. This, with spelter at 5½ cents a pound, would yield about $20 a ton on 40 per cent ore or $18 a ton on 38 per cent ore. The sphalerite middlings from the Wellington mill go to the Western Chemical Manufacturing Co., in Denver, which pays for the zinc and after separating the sphalerite utilizes the pyrite in acid making.

GENERAL CHARACTER OF THE FISSURING.

The district is far from being a favorable one for the study of fissure systems, owing to the soil-covered condition of the slopes and to the fact that the veins, having very little quartz in their composition, do not outcrop visibly and can not be traced by the eye over the surface. Moreover, as stated in the first part of this chapter, the conditions for underground study are fully as unsatisfactory as at the surface.

With no known exception, certainly with no important exception, the veins strike from east-northeast to northeast, showing in this respect rather remarkable uniformity. They thus cross nearly at right angles the general strike of the sedimentary formations. As Spurr and Garrey[1] have pointed out, this is the prevailing direction of the principal fissuring throughout the great Colorado mineral belt extending from Boulder County to the San Juan region.

The dips are more varied than the strikes and range generally from 45° to 90°. As a whole, the veins stand at fairly high angles and the average dip is probably near 65°. The important veins of the Wellington group and of Mineral Hill generally dip at angles ranging from 45° SE. to 90°. The usual dip is about 65°. The Minnie vein, where seen, dips 70° SE. The Old Reliable vein, where cut by the McLeod tunnel, near Lincoln, dips 75° SE. On the opposite side of French Gulch the Country Boy and Sallie Barber veins dip northeast at about 80°, while a vein cut near the face of the Helen tunnel and at least one small vein in the Country

[1] Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle, Colorado: Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 118.

Boy workings dip southeast at about 65°. The little veins of Farncomb Hill are generally steep. Most of those in the western part of the hill in the Ontario, Key West, and Boss mines dip northwest at 60° to 75°. Those in the eastern part of the hill, on the other hand, generally dip southeast at about the same angles. A few are practically vertical. In the Hamilton and Jessie mines the fissuring is complex and there are many subordinate intersecting systems. The dip of the dominant fissures, however, is northwest and the angles range from 45° to vertical. The Gold Dust and Puzzle veins are so nearly vertical that their general inclination was not determinable from the little that could be seen of them in 1909. The veins of the Washington mine are reported to dip to the northwest at 65° to 75°. The general dip of the Dunkin vein is southeast at 50°. The Laurium vein dips 70° in the same direction.

The principal fissures in the district are thus referable to a single conjugate system with strikes which range from east to north, but which, as a rule, are between east-northeast and northeast and with generally steep northwest or southeast dips.

The fissures are not of great length. The Wellington group of fissures has a total length of at least 1¼ miles. The Siam vein of this group is probably the largest lode in the district, but has not been proved to have a length of more than 1,200 feet, to which probably 400 feet more should be added for its faulted continuation—the Iron vein. The Dunkin vein has been opened continuously for 1,400 feet, the Puzzle vein for about 1,700 feet, and the Washington vein for fully 1,200 feet. The other veins known in the district are probably all shorter, so far as exploration has shown, than the ones mentioned. As they are not of great length, the veins evidently do not fill structurally important fault fissures—a conclusion amply borne out by their geologic relations and by the general absence of much triturated material between their walls. Concerning the behavior of the fissures at considerable depth, the underground workings as yet afford no data.

CLASSIFICATION AND DISTRIBUTION OF THE DEPOSITS.

In accordance with the usage of Beck[1] the word primary, as used in the heading of this chapter, implies essentially nothing more than a distinction from detrital or placer deposits. In this sense even such veins as may have undergone some so-called secondary enrichment in their upper parts are primary deposits as a whole.

To one having only a slight familiarity with the district the primary deposits might appear obviously susceptible of division into definite groups. Nothing, for example, could at first glance appear more different than the narrow gold-bearing veins of Farncomb Hill, generally less than an inch wide, and the great galena-sphalerite-pyrite veins of the Wellington mine, in French Gulch, or the low-grade stockwork of the Jessie mine, in Gold Run. Fuller knowledge, however, shows that the differences are largely matters of mere size and shape of relative proportions of constituents rather than of essentially distinct types or periods of mineralization, and that deposits apparently of wide diversity are connected by those of intermediate character. Thus there is a close relationship, although not much similarity, between the gold-bearing Farncomb Hill veins, in shale, and the Elephant ore body of the Wire Patch mine, on the south side of the hill, in porphyry. The latter in turn is in some respects not unlike the ore bodies of the Cashier mine, in Browns Gulch, and of the Jessie mine. Finally, the ore bodies of the Hamilton mine, in Summit Gulch, partly bridge the gap between the deposits of the Jessie and Wellington mines. Accordingly, any grouping artificially made must depend more on differences in the shapes of the ore bodies or in the relative proportions of the constituents than on essential differences in genesis. With this understanding the ore deposits of the Breckenridge district may be conveniently divided into (1) veins of the zinc-lead-silver-gold series; (2) stockworks and veins of the gold-silver-lead series; (3) the Farncomb Hill gold veins; (4) veins in the pre-Cambrian rocks; (5) metasomatic replacements, generally along the bedding planes, in sedimentary rocks; and (6) gold-silver deposits in the Dakota quartzite.

The deposits of the first class occur chiefly within the south half of the area mapped and are in their distribution closely related to the monzonite porphyry. Many are in this rock;

[1] Beck, Richard, Lehre von den Erzlagerstätten, 3d ed., Berlin, 1909.

others have the porphyry for one wall or are partly in porphyry and partly in the Dakota quartzite. In this group belong the ore bodies of the Wellington, Lucky, Minnie, Cincinnati, and other mines on the south slopes of Prospect and Mineral hills; of the Country Boy, Sallie Barber, and Little Sallie Barber mines, on the slope of Bald Mountain south of French Creek; of the Washington, Dunkin, and Juniata mines, on Nigger Hill; and of the Puzzle, Ouray, and Gold Dust mines, in the vicinity of Illinois Gulch. The formerly productive ore body of the Mountain Pride mine, near the head of Illinois Gulch, should probably be considered in this group, although it occurs in an area of sedimentary rocks; for the dumps show that there was monzonite porphyry associated with the ore.

In the second group are the ore bodies of the Jessie, Hamilton, Cashier, I. X. L., and Wire Patch mines. In the third group are the unique veins that traverse the north slope of Farncomb Hill. The fourth group includes the Laurium, Senator, Arctic, and Ling mines. In the fifth group are the Kellogg, Bullion King, Sultan, and other mines on Gibson Hill, and probably also, the Iron Mask mine. Finally, in the sixth group, not a very well defined one, are the Brooks-Snider and some other workings in Shock Hill, the ore pockets of Little Mountain, and possibly also the Golden Edge and Gold Bell mines, on Bald Mountain.

The meager facts ascertainable regarding the Jumbo, Extension, and Little Corporal mines are included in Chapter IX, on the veins of the zinc-lead-silver-gold series, although too little is known of these deposits to warrant their definite assignment to this series.

INDEX TO MINING CLAIMS.

The topographic map (Pl. II, in pocket) shows the location of the numerous claims in the district by a system of numbers. The district is divided into squares, which are indicated by letters and roman numerals on the margins, and the claims in each square are numbered, as indicated in the following lists:

Alphabetic list of claims shown in Plate II.

A VI C 32
Abbot Placer V B 9
Abby V F 9
Ada Placer VI A 1
Ada Placer V C 63
Adams Placer IV A 2
Adelaide IV D 62
Aggie VI C 22
Aggie IV D 41
Ajax VII E 29
A. Jay IV D 15
Alameda VI D 16
Albany III D 48
Albany V F 42
Alice A. IV B 62
Alice IV B 67
Alice VI D 55
Alice A. (M. S.) V B 19
Alice and Nellie Placer III F 38
Alliance IV B 51
Almira III E 2
Alpha Placer VI D 60
Alta VI E 6
American III D 82
American II F 2
American Placer IV A 1
American Placer (Survey 84) V G 2
American Placer (Survey 85) V G 1
Amulet III F 23
Andromeda V D 57
Anna IV B 47
Anna VI C 51
Ann Arbor VI D 36
Ann Arbor Placer VI D 35
Annex Placer VII D 7
Annie B. IV F 8
Annie C. III C 36
Annie Placer III A 7
A No. 1 V E 25
Antelope III E 36
Apex V A 27
Arab III C 20
Ardath IV D 49
Arling III C 4
Arraria V F 21
Arthur IV D 2
Arthur Nall VI E 2
Athol V C 12
Athos IV B 66
Atlantic VI C 46
Auckland V D 39
Australia Gulch Placer V D 68
Autocrat VI B 11
Autocrat Ex. VI B 12
Aye Kay IV F 2

B VI C 33
Bacon IV B 41
Baden Baden III C 17
Badger VI C 2
Badger III D 25
Bagdad III C 21
Baker VII E 11
Baldwin IV E 6
Baldwin M. S. IV E 5
Ballarat Placer II E 4
Ballard VI C 5
B. and L. No. 1 Placer II A 5
B. and L. No. 2 Placer IV A 3
Barbara IV B 45
Bartlett-Shock Placer V B 6
B. B. IV C 19
Bear V D 2
Bear Extension V D 1
Bed Rock IV B 21
Bed Rock Placer VI C 30
Bed Rock Placer II E 1
Belcher VI D 18
Belle III C 40
Belle V F 50
Belle of Baloy VI E 17
Belle of Swan III E 70
Bellevue VI D 29
Ben Butler V E 14
Ben Harrison VI C 20
Berlin III C 14
Berlin Placer VI C 45
Berten III E 17
Bertha D. III C 33
Bertie H. VI C 25
Bess V F 3
Bessie IV C 9
Beula IV A 17
Big Pan VI D 66
Big Sallie Barber VI D 39
Big Sallie Barber Ex. V D 74
Bill V E 12
Billie Button IV C 41
Bi-metallic III D 33
Birdie Treble VII C 5
Birdseye III E 16
Birdseye No. 1 III E 15
Birdseye No. 2 III E 14
Birdseye No. 3 III D 68
Black Bear V E 7
Black Prince VI E 23
Black Prince No. 2 VI E 29
Blackhawk VI E 44
Blaine IV D 1
Blaine III E 43
Blaine VI E 39
Blanche E. IV C 42
Blind Tom IV F 5
Blue IV C 44

Identification list of claims corresponding to coordinate squares and serial numbers in Plate II.

Square I A.

1. Morse Placer
2. Gold Wonder Placer

Square I B.

1. Gold Hill Placer
2. Du Lac Placer
3. Monroe Placer
4. Independence Placer
5. Kimballs Placer

Square I C.

1. Swans Nest Placer

Square II A.

1. Liberty Placer
2. Quartz Mountain Placer
3. Red Mountain Placer
4. Blue River Placer
5. Kate S. Placer
6. Band L. No. 1 Placer

Square II B.

1. Braddock Placer
2. Riley Placer
3. Mumford No. 1 Placer
4. Bryan Placer
5. Shekel Placer
6. Mumford No. 2 Placer

Square II C.

1. Kentucky Placer
2. Delaware Placer
3. Ohio Placer

Square II D.

1. Davenport Placer
2. Iowa Placer
3. Galena Placer
4. Queen Placer

Square II E.

1. Bed Rock Placer
2. Hamilton

Square II E—Continued.

3. Summit Placer
4. Ballarat Placer
5. Galena
6. Ledge
7. Me Next
8. Midnight Placer

Square II F.

1. Williams Placer
2. American
3. Central American

Square III A.

1. Gold Eagle Placer
2. Napoleon Placer
3. Sam Blair Placer
4. Climax Placer
5. Revenue
6. Legal Tender
7. Annie Placer
8. Washington Placer
9. Lafayette Placer
10. Coyne Placer

Square III B.

1. Red Rover
2. Bonnie Nelson
3. Fairview Placer
4. Golden Age Placer
5. Mumford No. 4 Placer
6. Mumford No 3 Placer
7. Excelsior Placer

Square III C.

1. Peabody Placer
2. Jessie
3. Discovery Ex.
4. Arling
5. F. P. D.
6. C. B. and Q.
7. Dixie
8. Gold Run No. 1
9. Hattie
10. Discovery
11. Dash Warn
12. I. X. C. O.
13. Glenwood
14. Berlin
15. Fraction
16. May B.
17. Baden Baden
18. Valley
19. Bullion
20. Arab
21. Bagdad
22. Jessie
23. Caliph
24. Damascus
25. John Shock
26. Egypt
27. Fellah
28. Slide
29. Loop
30. Columbia
31. Cecil C.
32. Cora E.
33. Bertha D.
34. Minnie L.
35. Clara L.
36. Annie C.
37. Lottie B.
38. Florence
39. Toledo
40. Belle
41. Chicago
42. H. B. D.

Square III D.

1. Dania
2. Irene C.
3. Helen G.
4. Jane S.
5. Mollie B.
6. Mary G.
7. Girlie B.
8. Emma L.
9. E. G. G.
10. Laura H.
11. Sin San
12. Summit
13. K. T.
14. John Bell
15. Lafe Pence
16. Weaver
17. Galena
18. Ergo
19. Swan
20. Ironside
21. July
22. Gold Bug
23. White Cloud
24. Camp Bird
25. Badger
26. Electra
27. June Bug
28. Little Betsey
29. Gold Flake
30. Wolftone
31. Coin
32. Nelson
33. Bi-metallic
34. Summit
35. Yellow Jacket
36. Crown Point
37. Fraction
38. Gov. Waite.
39. Populist
40. Nelson Ex.
41. Reservoir Placer
42. Delaware
43. Delaware No. 1
44. Delaware No. 2
45. Bryan
46. Triangle
47. Newport
48. Albany
49. Eagle
50. Nil Desperandum
51. Gold Bug
52. Blue Bird
53. Muddy
54. Gold Brick
55. Gold Cord
56. Giant
57. Giantess
58. Lincoln
59. Grant
60. Hayes
61. Garfield
62. Burlington
63. Wheaton
64. J. I. C.
65. Grubstake No. 3
66. Grubstake No. 2
67. Grubstake No. 1
68. Birdseye No. 3
69. Outlet Placer
70. Clipper
71. Joe Davis
72. Smooth
73. Emadin
74. Free and Easy
75. Sherman
76. Merrimack
77. Kansas
78. Grey Eagle
79. Muldoon

Square III D—Continued.

80. Monitor
81. Gen. Butler
82. American
83. Star Spangled Banner
84. Stars and Stripes

Square III E.

1. Storms Placer
2. Almira
3. Clara
4. Prairie Dale
5. Don Juan
6. Free Gold
7. Free Gold No. 2
8. Free Gold No. 3
9. Maple Leaf
10. Cache
11. Logan
12. Clifton
13. Clifton M. S.
14. Birdseye No. 2
15. Birdseye No. 1
16. Birdseye
17. Berten
18. Lookout
19. Jasper
20. Chester
21. Homestake
22. O. K.
23. Boston
24. Blue Bird
25. Pioneer
26. Emmet
27. Knorr
28. Charlie W.
29. Gissee
30. Rain
31. Cloud
32. Storm
33. Fog
34. Fawn
35. Doe
36. Antelope
37. Deer
38. Elk
39. Sherman
40. McKinley
41. Rollins
42. Garfield
43. Blaine
44. Webster
45. Clay
46. Weaver
47. McMc
48. Gulch
49. Pick
50. Hammer
51. Gad
52. Venus
53. Comet
54. Luna
55. Mars
56. North Star
57. Jupiter
58. Castor
59. Pollux
60. Sirius
61. Lyra
62. Lulu
63. Tennessee
64. Sadie
65. Caribou
66. Reindeer
67. Moose
68. Valmy
69. Gertie Corey
70. Belle of Swan
71. Little Deber

Square III E—Continued.

72. Climax No. 4
73. Climax No. 2
74. Climax No. 3
75. Nellie
76. Peerless
77. Woodland Placer

Square III F.

1. South America
2. Paymaster
3. Last Chance
4. Sheridan
5. St. Louis No. 1
6. St. Louis No. 2
7. St. Louis No. 3
8. Staunton No. 3
9. Staunton No. 1
10. Mammoth
11. Cashier M. S.
12. Smuggler
13. Cashier
14. Morning Star
15. Ida M.
16. Ida M. No. 2
17. Ida M. No. 3
18. Muldoon
19. Mineral Chief
20. Wood No. 2
21. Wood No. 1
22. Brown Placer
23. Amulet
24. Sallie Lewis
25. Eureka
26. Last Chance Ex.
27. Highland Mary
28. Royal Tiger
29. I. X. L.
30. Swallow
31. Longfellow
32. British Boy
33. Swan King
34. O. J. Lewis
35. Teddy
36. Silver Eel
37. I. X. L. Placer
38. Alice and Nellie Placer
39. New Discovery
40. Sue
41. Primrose Placer
42. Brewery Placer

Square III G.

1. Mascot Placer

Square IV A.

1. American Placer
2. Adams Placer
3. B. and L. No. 2 Placer
4. Protector Placer
5. Quartz Placer
6. Masonic Placer
7. Sunset
8. New Year.
9. Friendship
10. Bull Dog
11. Summit No. 2
12. Summit
13. Summit No. 1
14. Morningside
15. Quartz Mountain
16. Ten Strike
17. Beula
18. Side Line
19. Lone Hand
20. Double Header
21. Chesapeake
22. Harold Placer

Square IV A—Continued.

23. Elyria M. S.
24. Iron Mask
25. High Five
26. Dora L.
27. Gold Dust Placer
28. Hazel Placer
29. Germania

Square IV B.

1. Magnum Bonum Placer
2. Shakespeare
3. Ella
4. Edna
5. Eagle
6. St. Paul
7. Fox Lake
8. Ira Roberts
9. Lincoln
10. Hayes
11. Diana
12. Sultana
13. W. B. Stephenson
14. Silver Boom
15. Breckenridge
16. Como
17. Cleveland
18. Mollie B.
19. Fraction
20. Lot No. 5
21. Bed Rock
22. Lot No. 4
23. Stonewall Jackson
24. Lot No. 3
25. Snow-bank
26. Lot No. 2
27. George Washington
28. Cleveland Placer
29. Rosa
30. Lake Superior Placer
31. Quality Hill
32. Salina
33. Romance
34. Tiptop
35. Mastodon
36. Morning Star
37. Hindoo
38. Little Corporal
39. Kiowa
40. Burnsides
41. Bacon
42. Hattie M.
43. Rose F.
44. May W.
45. Barbara
46. Elizabeth
47. Anna
48. Mathilda
49. Elenora
50. Princeton
51. Alliance
52. Stark
53. Snow-storm
54. Paris
55. Little Maud
56. Bullion King
57. Parallel
58. Plow Boy
59. Company
60. Chantilly
61. Wicklow
62. Alice A.
63. Rosslyn
64. Canfield
65. Crœsus
66. Athos
67. Alice
68. Jack
69. R. A. Gardner

Square IV B—Continued.

70. Harrison
71. Morton
72. Mary Gardner
73. Three Brothers
74. Georgetown Miner
75. Leona
76. Mountain Lion
77. Kate
78. Eureka
79. Blue River
80. Iron
81. Franklin
82. Naperville
83. Huron Placer
84. Shamrock
85. Dirigo
86. Company No. 2

Square IV C.

1. Gold Run Placer
2. Jumbo
3. Buffalo
4. Small Hopes
5. Last Chance
6. Sundown
7. Cleveland
8. Small Spot
9. Bessie
10. Jessie
11. Lottie May
12. San Francisco
13. San Francisco No. 2
14. San Francisco No. 3
15. Standard No. 1
16. Standard No. 2
17. Nahant
18. Ethelena
19. B. B.
20. Intrepid
21. Volunteer
22. Thistle
23. Kensington Placer, Tract A
24. Double Ex.
25. Consolidation
26. Deadwood
27. Hendrix
28. Treble Ex. S. W.
29. Mascot
30. Teller
31. Queen of the West
32. Chance
33. Little Joe
34. Little Dick
35. Sundown Placer
36. Detroit Placer
37. Carpenter Placer
38. Dry Gulch Placer
39. Buffalo Placer
40. Old Tom
41. Billie Button
42. Blanche E.
43. June Bug
44. Blue
45. Ruth
46. Nickel Plate
47. Hidden Treasure No. 1
48. Hidden Treasure No. 2
49. Langdon No. 2
50. Chester
51. Monitor
52. Magnet
53. Wyneta
54. Mineola
55. Fraction
56. Detroit
57. St. Lawrence
58. Pelican

Square IV D.

1. Blaine
2. Arthur
3. Harrison
4. Cleveland
5. Morton
6. McKinley
7. Bryan
8. Denver
9. Cripple Creek
10. Leadville
11. Breckenridge
12. Emma
13. Summit
14. Willie V.
15. A. Jay
16. Gold Run
17. Trench
18. Little Harry
19. Gold Hill
20. Carbonate
21. Hematite
22. Cleopatra No. 1
23. Cleopatra
24. Cleopatra No.
25. New York
26. Brooklyn
27. Oregon
28. Iowa
29. Texas
30. Gloucester
31. Schley
32. Lightburn
33. Whale
34. Lucile
35. Mammoth
36. Little Harry
37. Ironside
38. O. K.
39. Florence
40. Buffalo
41. Aggie
42. Ellsworth
43. Lucky
44. Gold Standard
45. Climax
46. Treasure
47. Janice
48. Maurine
49. Ardath
50. Boy
51. Thelma
52. Wormwood
53. Carvel
54. Harum
55. Helen Placer
56. Golden Gate Placer
57. Unicorn Placer
58. Grey Horse
59. Brisbane
60. Sidney
61. Melbourne
62. Adelaide

Square IV E.

1. Wellington Placer
2. Harum Placer
3. Golden Rule
4. Manilla
5. Baldwin M. S.
6. Baldwin
7. Smith Placer
8. Miller Placer
9. Virtotus Placer, Lot A

Square IV F.

1. Treasury
2. Aye Kay
3. Joe Gliddon
4. Walker Placer
5. Blind Tom
6. Erie
7. Libbie K.
8. Annie B.
9. Tosie C.
10. Florence
11. Humbug
12. Georgia
13. Erie
14. Magnet
15. Wilderness
16. Golden Calf
17. Israelite
18. Egypt
19. Fuller and Greenleaf Placer (Survey 83)

Square IV G.

1. Eckhart Patch Placer
2. Miller Placer
3. Excelsior Placer

Square V A.

1. Boom Placer
2. Wildcat No. 5
3. Wildcat No. 4
4. Wildcat No. 3
5. Wildcat No. 2
6. Wildcat No. 1
7. Ground Hog No. 3
8. Ground Hog No. 2
9. Ground Hog No. 1
10. Cucumber Patch Placer, Tract C
11. Brooks-Snider M. S.
12. Peerless
13. Fannie Barrett
14. Illinois
15. Iowa
16. Bonanza
17. Regent
18. Vermont
19. Clifton
20. California
21. Nevada
22. Virginia
23. Eldorado
24. Colorado
25. Idaho
26. Ohio
27. Apex
28. Union
29. Peerless
30. Cucumber Patch Placer, Tract D
31. Cucumber Patch Placer, Tract B
32. Pennsylvania
33. Cucumber Patch Placer, Tract A
34. Lomax Gulch Placer
35. Sawmill Patch Placer
36. Hunt Placer
37. Metcalf Placer
38. Dennison Placer
39. Jersey Placer
40. Traction Placer

Square V B.

1. Rankin Placer
2. Engle Placer
3. Columbia
4. Louisa

Square V B—Continued.

5. Snider Placer
6. Bartlett-Shock Placer
7. Corkscrew Placer
8. Silverthorn Placer
9. Abbott Placer
10. Bonanza Placer
11. Blue River Placer
12. French Gulch Placer
13. Blue River
14. Blue River No. 2
15. Cleveland Placer
16. Sisler Placer, Tract B
17. Myrtle Annie
18. New York No. 1
19. Alice A. (M. S.)

Square V C.

1. New York No. 2
2. New York No. 3
3. New York No. 4
4. New York No. 8
5. New York No. 9
6. New York No. 5
7. New York No. 6
8. New York No. 2
9. Johannesburg
10. Eunice Bell
11. Hazel Kirk
12. Athol
13. Cosie D.
14. Rosewater No. 3
15. Chicago
16. Milwaukee
17. St. Paul
18. Rosewater No. 2
19. Rosewater No. 1
20. Little Daisy
21. Roosevelt No. 1
22. Roosevelt No. 2
23. Roosevelt No. 3
24. Lightning
25. Lightning No. 1
26. Sidney
27. Mogul
28. Virginia
29. Ketman
30. Union
31. Smuggler
32. Silent Friend
33. Old Union
34. Iron Mask
35. Dirigo
36. Simcoe
37. Rising Moon
38. Cuba
39. Langdon
40. Oxford
41. Klondyke
42. Miller
43. Brown
44. Charlie
45. Georgie
46. Maybell
47. Dandy
48. Boss
49. Little Lizzie
50. Colorado
51. Silver Head
52. X. 10. U. 8. No. 2
53. X. 10. U. 8
54. Mono
55. Havana
56. Prize Box

Square V C—Continued.

57. Diamond Dick
58. Chief
59. Siam
60. Oro
61. Louis D. Placer
62. Stillson Patch Placer
63. Ada Placer
64. Sisler Placer, Tract A
65. Ford Placer
66. O
67. N
68. M
69. Johannesburg Placer
70. Kensington Placer, Tract B

Square V D.

1. Bear Extension
2. Bear
3. Virtue
4. Charity
5. Hope
6. Faith
7. McKinney
8. Wellington
9. Wellington Ex.
10. Liberty
11. Wellington No. 2
12. Truax
13. Wellington No. 3
14. Cross
15. Czar
16. Merry Gold
17. Orthodox
18. Orthodox M. S.
19. Orthodox No. 2
20. Orthodox No. 3
21. Great Northern
22. Carrie La Salle
23. Cub
24. Brown M. S.
25. Rose of Breckenridge
26. Brownie Birdie
27. Nutmeg
28. Ella
29. Tom Price
30. Tecumseh
31. Snow-drift
32. Rose of Breckenridge
33. Kathleen
34. Mavourneen
35. Fraction
36. Sam Clark
37. Davis
38. Dunedin
39. Auckland
40. Minnie
41. Greenwood
42. Deadwood
43. White Pine
44. Robley
45. Old Tennessee
46. Waters
47. Peoria
48. Cassiopeia
49. Cincinnati
50. Jackson M. S.
51. Lucky
52. Paducah
53. Kentucky
54. Mattie
55. Buckeye
56. Dic Vernon
57. Andromeda
58. Silver Star
59. Emilie Placer
60. Country Boy

Square V D—Continued.

61. Devil
62. Modoc
63. Maid of the District
64. Hopeful
65. Helen No. 0
66. Helens Baby
67. Helen No. 1
68. Australia Gulch Placer
69. Lone Bub
70. Edna
71. Leona
72. Little Sallie Barber Ex.
73. Sallie Barber
74. Big Sallie Barber Ex.
75. V
76. Streng
77. Outlet

Square V E.

1. Virtotus Placer
2. Mineral Hill
3. St. Paul
4. John J. Placer
5. Polar Bear
6. Brown Bear
7. Black Bear
8. White Bear
9. Hunt a Name
10. Great West
11. Tom
12. Bill
13. Ocean Wave
14. Ben Butler
15. Governor King
16. Celtic
17. Richmond
18. Juventa
19. Christina
20. Monitor No. 1
21. Monitor
22. Fair Chance
23. Reliable
24. Friday
25. A No. 1
26. Lizzie Moore
27. O. K.
28. Golden Gate
29. Comet No. 2
30. Cobb and Ebert Placer
31. Lakota Placer
32. Rochester
33. Buffalo
34. New York
35. Virginia City
36. Butte City
37. James G. Carlisle
38. Roger Q. Mills
39. Clara W.
40. Ella G.
41. Hanna
42. Horton

Square V F.

1. Forest Queen
2. Patti
3. Bess
4. Comet No. 1
5. Telephone Girl
6. Comet
7. Hillside
8. Producer
9. Abby
10. Judson
11. Comet No. 3
12. Comet No. 4
13. Happy Jack

Square V F—Continued.

14. Thornton
15. Daisy
16. Edna
17. Emma
18. Sue
19. Old Joe
20. Conclave
21. Arraria
22. Pearl
23. Comet
24. Ontario
25. Little Morgan
26. Queen of the Forest
27. Triangle
28. Emperor
29. Elephant
30. Frederick the Great
31. Wire Patch Placer
32. Key West
33. Boss
34. Virginia
35. Reveille
36. Gladstone
37. Magic
38. Mt. Royal
39. Eldorado
40. Julia
41. Last Dollar
42. Albany
43. Rochester
44. Matchless
45. Sunnyside
46. Clark Placer
47. Vienna Placer
48. Kingfisher
49. Kit Carson
50. Belle
51. Little Erny
52. Pontoon
53. Enterprise
54. Max
55. Climax
56. Windy Gap Placer

Square V G.

1. American Placer (Survey 85)
2. American Placer (Survey 84)
3. Puzzler
4. Iron Mask
5. Delta Placer
6. Mountain Lion
7. Dictator No. 1
8. Dictator No. 4
9. Mulberry Placer

Square VI A.

1. Ada Placer
2. Tyra Placer
3. F. and D. Placer
4. Lake Placer
5. Sundown Placer
6. Dix Placer

Square VI B.

1. Fanny Placer
2. Riverside Placer
3. Maggie Placer
4. South Side Placer
5. Klack Gulch Placer
6. Hermit Placer
7. Floradora Placer
8. Tiger
9. Ocean Wave
10. Silver Dick

Square VI B—Continued.

11. Autocrat
12. Autocrat Ex.
13. Elkhorn
14. New England Placer
15. Combination
16. Foote
17. Conrad
18. South Etigrade
19. South Elkhorn
20. Contact
21. Nannie Houston
22. May
23. Germania
24. Lizzie
25. Silver Group No. 1
26. Silver Group No. 2
27. Silver Group No. 3
28. Silver Group No. 4
29. Troy
30. Nellie Placer

Square VI C.

1. Monarch
2. Badger
3. Elk
4. Moose
5. Ballard
6. Chicago
7. Hidden Treasure
8. Bright Hope
9. Chippewa
10. Moonstone
11. Windsor
12. Redwing
13. Maxwell
14. Commodore Placer
15. Hillside
16. Price
17. Page
18. Wolftone
19. Old Ironsides
20. Ben Harrison
21. Countess
22. Aggie
23. Maggie
24. Juniata Ex.
25. Bertie H.
26. Evening Star
27. Morning Star
28. Oreornogo
29. Juniata
30. Bed Rock Placer
31. T. H. Fuller Placer
32. A
33. B
34. C
35. D
36. L
37. K
38. J
39. I
40. H
41. G
42. F
43. E
44. Uncle Sam
45. Berlin Placer
46. Atlantic
47. Washington
48. Emmett
49. Standard
50. Bulwer
51. Anna
52. Eva
53. Graphic
54. Tecumseh
55. Ouray

Square VI C—Continued.

56. Puzzle
57. Last Chance
58. Cliff
59. Little Callie
60. Hannibal and St. Joe
61. Scott
62. Vandalia
63. Grouse
64. Little Tom
65. Slide
66. Dewey
67. Fargo
68. Conquest
69. Confidence
70. Conjecture
71. Compromise
72. Lone Star
73. Illinois Placer
74. Gold Dust
75. Pacific
76. Rub
77. Watson Placer
78. Pittsburg Placer
79. Helen B.
80. Silver Group No. 5
81. West Point
82. Carpenter Placer
83. Fugitive

Square VI D.

1. Lennox
2. U
3. T
4. S
5. R
6. Q
7. Bunker Hill
8. Independence
9. St. James
10. Silver King
11. Dry Placer
12. Jerusalem Placer
13. Eclipse No. 1
14. Eclipse
15. Kentucky
16. Alameda
17. California
18. Belcher
19. Cadiz
20. Mexican
21. Last Chance Placer
22. Crœsus No. 0
23. Crœsus No. 1
24. Crœsus No. 2
25. Crœsus No. 3
26. Crœsus No. 4
27. Crœsus No. 5
28. Crœsus No. 6
29. Bellevue
30. Dreadnaught No. 1
31. Dreadnaught
32. Nellie H.
33. Michigan
34. Empire
35. Ann Arbor Placer
36. Ann Arbor
37. Brown
38. Little Sallie Barber
39. Big Sallie Barber
40. First Discovery
41. Cumberland
42. Halifax
43. Gen. Jackson Placer
44. Gold Pan
45. Riddle Placer
46. Helena Placer
47. Helena

Square VI D—Continued.

48. Helena No. 2
49. Helena No. 3
50. Helena No. 4
51. Excelsior
52. Laurium
53. Walker
54. Dexter
55. Alice
56. Laurium No. 2
57. Laurium No. 3
58. Star Placer
59. Gold Pan No. 2
60. Alpha Placer
61. New Market
62. Delta
63. McKinley
64. Gold Coin
65. King
66. Big Pan
67. Pi
68. Pi No. 2
69. Pi No. 3

Square VI E.

1. Cecil
2. Arthur Nall
3. Dew Drop
4. Keystone
5. Rising Sun
6. Alta
7. Clara Belle
8. Crown Point
9. White Top
10. Three Links
11. Lady Huntington
12. King Solomon
13. Grouse
14. Reynolds
15. Rose Lee
16. Tunnel
17. Belle of Baloy
18. Mount Nebo
19. Keystone
20. Jim Crow
21. Little Chief
22. Indian Girl
23. Black Prince
24. Silver Cup
25. Gold Belle
26. Eagle No. 3
27. Eagg
28. Eagle
29. Black Prince No. 2
30. Silver Cup No. 2
31. Gold Belle No. 2
32. Golden Edge Placer
33. Denver
34. Shamrock No. 2
35. Shamrock
36. Vigilant
37. Wisconsin
38. B. V.
39. Blaine
40. Golden Edge No. 3
41. Golden Edge No. 4
42. Golden Edge
43. Flagstaff
44. Blackhawk
45. Golden Edge No. 2
46. Little Tommie
47. Lakota Placer
48. Little Chief No. 2
49. Knob No. 3
50. Knob No. 2
51. Knob No. 1
52. Knob No. 4
53. Knob No. 5

Square VI E—Continued.

54. Knob No. 6
55. Stevens & Baker No. 3
56. Stevens & Baker No. 2
57. Stevens & Baker No. 1
58. Stevens & Baker No. 4
59. Stevens & Baker No. 5
60. Stevens & Baker No. 6
61. Carbonate No. 2

Square VI F.

1. Capt. Ryan Placer
2. Nebraska Placer
3. Upper Ten
4. Goldenrod
5. Cornucopia

Square VI G.

1. Log Cabin
2. Evening Star
3. Kittie M.
4. Morning Star
5. Guyot Placer
6. Dictator No. 2
7. Dictator No. 3
8. Me Too

Square VII A.

1. Evans Placer
2. Dewey Placer

Square VII B.

1. Gold King Placer
2. Gold King No. 1 Placer
3. Nellie Placer
4. Crown Placer
5. Iron
6. St. Louis
7. Lucky
8. Golden Crown Placer

Square VII C.

1. Independence
2. Fourth of July
3. Rocky Point
4. Siphon
5. Birdie Treble
6. Rocky Point Placer
7. Park Placer
8. Gold Nugget Placer
9. Gold Nugget No. 2 Placer

Square VII D.

1. Johnson
2. West Laurium
3. Illinois Placer
4. Laurium Placer
5. Neglected Placer
6. Terrible
7. Annex Placer.
8. St. Louis
9. Chicago
10. Waltham No. 2
11. Waltham No. 1
12. Williamsport
13. Mountain Pride
14. Gen. Grant
15. Lincoln

Square VII E.

1. Denver City
2. New York
3. Vulcan No. 1
4. Vulcan
5. Vulcan No. 2
6. Vulcan No. 3
7. O. I. C.
8. Little Sarah
9. Maggie
10. Twin Sisters
11. Baker

Square VII E—Continued.

12. Little Tommie No. 2
13. Little Tommie No. 3
14. Little Tommie No. 4
15. Highland Mary
16. Gold King
17. Gold Nugget
18. Pony Express
19. Harry S.
20. Lot 4
21. St. John No. 3
22. St. John No. 2
23. St. John No. 1
24. Carbonate
25. Doubtful
26. Kate
27. Lion
28. Tiger
29. Ajax
30. Juventa
31. Jove
32. Young America
33. Morning Star
34. Monument
35. Double Standard
36. Morning Star
37. Emma
38. Ina
39. Glenn

Square VII F.

1. Convent
2. Kate Elo
3. Lady of the Mountain
4. Florence
5. Semper Idem Placer

Square VII G.

1. Derry Placer
2. Bonanza
3. Minnie B.

CHAPTER IX.

VEINS OF THE ZINC-LEAD-SILVER-GOLD SERIES.

GENERAL FEATURES.

PLAN OF DESCRIPTION.

Owing to the condition of most of the mines in the district, full description of the zinc-lead-silver-gold veins is very nearly confined to an account of what may be seen in the Wellington workings. In order to avoid repetition it appears best under these circumstances, after a brief summary of some of the common characteristics belonging to the veins of this group, to proceed at once to a description of the Wellington ore bodies as constituting the most important examples of the type now open to investigation. This will be followed by such brief notes as may be presented concerning other mines whose ore bodies belong to the same group.

DISTRIBUTION.

The general distribution of the zinc-lead-silver-gold veins and their close connection with the monzonite porphyry was indicated in Chapter VIII. All lie in the southwest half of the mapped area and nearly all are within or very near the great mass of monzonite porphyry that makes up most of Bald Mountain, together with Nigger, Prospect, and Mineral hills. On Prospect and Mineral hills are the veins of the Wellington, Truax, Ella, Minnie, Cincinnati, Lucky, and Melbourne mines, all traversing monzonite porphyry and all typical members of the class. Across French Gulch are the Dunkin, Juniata, and associated veins in the monzonite porphyry of Nigger Hill; the Sallie Barber vein, on Bald Mountain, in porphyry; and the Country Boy and Washington veins, traversing porphyry and quartzite. South of Illinois Gulch are the Puzzle-Ouray and Gold Dust veins, in monzonite porphyry, quartzite, and shale. Of the Mountain Pride vein little is known, but it apparently belongs to the zinc-lead-silver-gold series. It differs from the others mentioned in having the "Wyoming" formation for its general country rock, with some monzonite porphyry, as the dumps show. On the north side of Gibson Hill are the Jumbo and accompanying veins, virtually at the northern limit of the monzonite porphyry. These veins consist of oxidized gold ore near the surface and change to pyritic deposits below. It is questionable whether they belong to the same class as the other veins mentioned, but too little can be learned about them to set them up as a distinct type. In some respects they appear to be intermediate between veins like those of the Puzzle mine and deposits like those of the Jessie mine.

ATTITUDE.

The general northeast strike of the veins and their various dips have already been mentioned. To this group belong all the large deposits of distinctly veinlike form found in the district except the Laurium vein in the pre-Cambrian. In this connection it is well to remember that classification is artificial, and that some of the lodes in the group now being described may extend down into the pre-Cambrian rocks and if the region were more deeply eroded would be put in the same class as the Laurium vein.

RELATION TO FAULTING.

It does not appear that any of the veins of the zinc-lead-silver-gold series occupy the fissures of important faults. Some movement undoubtedly took place when the fissures were first opened, for many of them were partly filled with brecciated and triturated material that was afterward replaced by sulphides. Moreover, the movement continued during and after the period of ore deposition; but careful mapping has failed to show that the distribution of the rocks as seen at the surface was appreciably affected by this movement. Although the veins fill fault fissures, the faulting was negligible so far as the general structure of the district is concerned. This is not at all peculiar to this region but appears to be a relation between fissuring and ore deposition that is exceedingly common. Great fault fissures are rarely filled by veins, perhaps chiefly because great movement tends to pack the fissure tightly with compressed impervious attrition material, and if ore is deposited at all it is likely to be crushed and dispersed through the gouge by the recurrent movements characteristic of great dislocations. On the other hand, productive veins often accompany great faults and fill the minor associated fissures.

WIDTH.

The width of the veins ranges up to a maximum of about 15 feet, attained by the Siam vein. As a whole, the stopes on the Mineral Hill veins range from 4 to 10 feet. The unusually wide parts of the veins are as a rule not all ore but generally contain one or more horses of waste. The single stope opened in 1909 on the Country Boy vein showed a maximum width of 5 feet. One drift in the Gold Dust workings was carried in places to a width of 20 to 24 feet, but some of the miners who ran it report, apparently with truth, that the vein did not attain anything like that width.

MATERIAL.

The vein material of this group varies widely in composition. As a rule, the sulphides predominate and such gangue as may be present is ordinarily a carbonate approaching siderite in composition. Quartz is almost absent from most of the veins, but the ore of the Gold Dust vein is in part siliceous, although the quartz is cryptocrystalline and represents the silicification of crushed quartzite and shale rather than the free development of quartz in open fissures. A similar cryptocrystalline quartz gangue was noted also in a small spur from the Puzzle vein, in quartzite. One of the simplest vein fillings is that of the Country Boy, where stoping was in progress in 1909. Here the material is chiefly dark sphalerite in massive aggregation with wholly subordinate siderite and a little pyrite and galena. Toward the ends of the pay shoot this ore becomes more pyritic. In some of the upper workings also galena was more abundant than in the part of the vein now worked. The Wellington veins are generally filled with a massive aggregate of galena, sphalerite, and pyrite in various proportions, with a very small proportion of siderite. In some places the veins contain essentially a lead ore; in others a zinc ore. The galena is invariably argentiferous and its quantity is generally a good index of the proportion of silver in the ores. The ores from the French Creek mines belonging to the zinc-lead-silver-gold series do not carry much gold, the ore from the Wellington rarely containing as much as a tenth of an ounce to the ton. On the other hand, the Gold Dust and Puzzle ore may contain from 20 to 25 ounces of silver and up to an ounce of gold to the ton. Some pyritic concentrates from the Gold Dust vein are stated to have yielded 17 ounces of silver and 2.5 ounces of gold to the ton.

The veins exhibit scarcely any regularity in the arrangement of their constituents, which are as a rule confusedly and intimately mingled in one structureless aggregate. In parts of the Siam and other veins of the Wellington group the ore is banded, but this is due not to any original order of deposition of the sulphides but to a late fissuring of the ore parallel with its walls and an infiltration of siderite or other carbonate into the small cracks thus formed. A specimen of ore traversed by one of these later veinlets is shown in Plate XXV, *B*. Although the ore of the zinc-lead-silver-gold veins rarely shows conspicuous brecciation, its structure in many places suggests that the deposits of brittle sulphides with their many surfaces of contact have from time to time been fractured and loosened by slight movements along the vein fissure and that fresh deposition of sulphides has then taken place, accompanied probably by some solution also of the older sulphides. Thus the whole deposit, while not showing any regular or definite succession of younger generations of minerals upon older ones, represents the final result of a complex series of depositions following closely upon each period of fracturing.

LATE MOVEMENTS.

The veins generally are not much broken by recent movement and are not accompanied by much gouge. In many places the sulphides are adherent to both walls, even where the veins are several feet wide. In some places, however, there is a seam of clay gouge along one or both sides of the ore. This material varies with the country rock but is generally a tough unctuous clay some of which contains many minute crystals of pyrite that apparently have formed in the gouge itself.

The veins are here and there displaced by later cross faults, as in the Wellington mine (p. 131), where there are two sets of such faults. Near these there is likely to be much local disturbance, the ore being broken and traversed by fissures filled with gouge. Unfortunately the conditions for studying displacements of the veins are in this district exceedingly unsatisfactory, the Wellington being the only mine that is at all illuminating as regards late faulting.

OXIDATION.

The general subjects of oxidation and enrichment are treated in another place. It will suffice to note here that the veins of the group under consideration oxidize as a rule to soft, earthy lead-carbonate ores, many of which are rich in silver. Exceptionally there is a notable concentration of gold near the surface. One of the first signs of oxidation in these veins is the occurrence of smithsonite in amorphous spongy form in the sphalerite, as shown in Plate XXVI, *A*.

EXAMPLES OF ZINC-LEAD-SILVER-GOLD DEPOSITS.

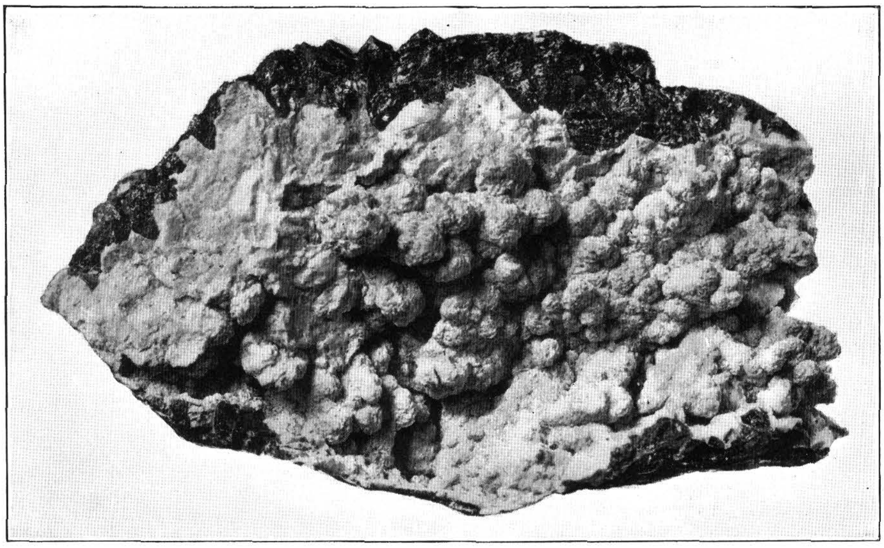
WELLINGTON MINE.

INTRODUCTION.

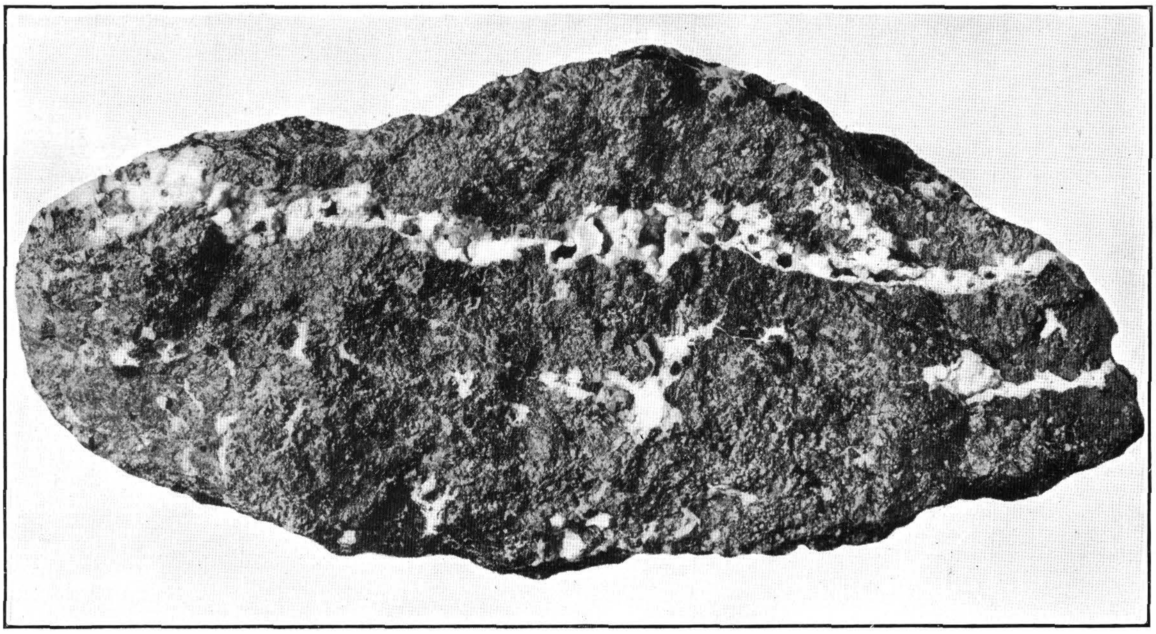
The Wellington mine (see Pl. XXVII, *A*), owned by the Wellington Mines Co., the stock of which is held largely in Kansas City, Mo., is situated on the north side of French Gulch, 2 miles east of Breckenridge. The property represents a consolidation of the Oro and original Wellington mines, which was effected in 1902 by the organization of the Colorado & Wyoming Development Co. The present corporation, capitalized at $10,000,000, acquired the mines about five years later, the sale of stock being helped by very alluring reports of the mines' resources. The Oro appears to have become productive about the year 1887, and in 1890 it was yielding more ore than any other mine in the district. The Wellington was opened shortly after the Oro but never attained the same prominence as its neighbor. The early shipments were argentiferous lead ore, including both cerusite and galena, the zinc ore at that time being regarded as waste. The total production of the two mines prior to their acquisition by the present company is not accurately known but is generally supposed to have been about $1,500,000.

In 1909 the Wellington Mines Co. was shipping daily about 25 tons of galena concentrates and from 8 to 10 tons of middlings consisting chiefly of sphalerite and pyrite. Shipments of crude ore and of high-grade sphalerite concentrates are also made from time to time. The first-class galena concentrates are bought by the Chamberlain-Dillingham Ore Co. and shipped to the smelters of the American Smelting & Refining Co. Concentrates containing over 30 per cent of zinc and generally under 10 per cent of iron go to several smelters in Missouri, Oklahoma, and Kansas. The middlings are bought by the Western Chemical Manufacturing Co., of Denver, which pays for the zinc and uses the pyrite for making acid.

The present mill, built in 1908, is situated near the portal of the Oro level. It is equipped with a jaw crusher, three sets of Morse rolls, Callow screens, six 6-compartment Harz jigs, and four Wilfley tables. In general the products are (1) galena concentrates; (2) the so-called "middlings," including sphalerite concentrates that are purposely mixed with material containing much pyrite; and (3) tailings, in which is included pyritic material from the third compartment of each jig.

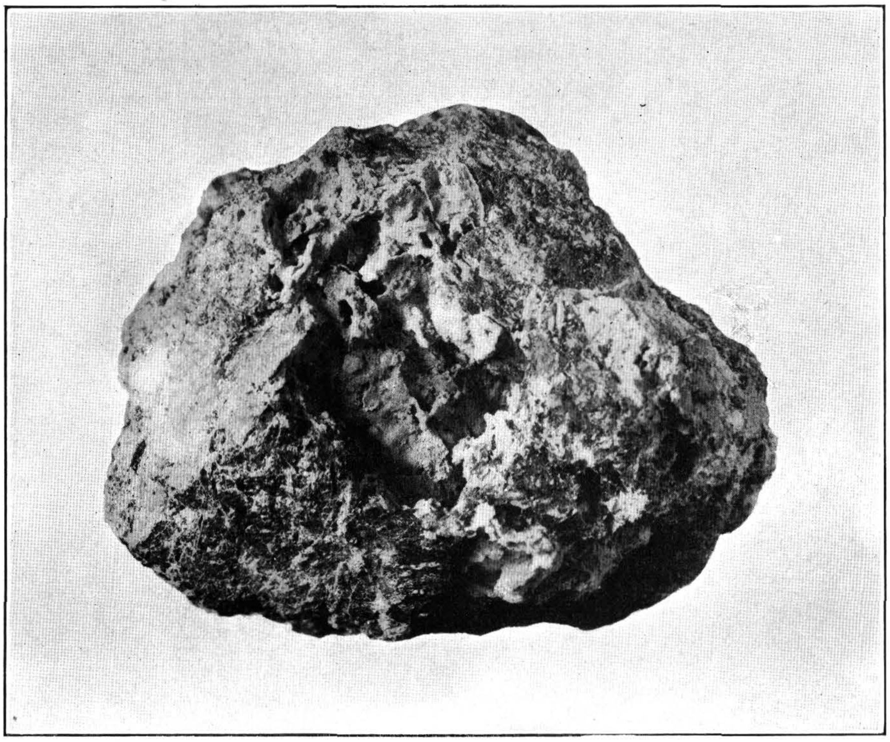


A. INCRUSTATION OF SIDERITE IN A VUG IN SPHALERITE.
Natural size. See page 87.



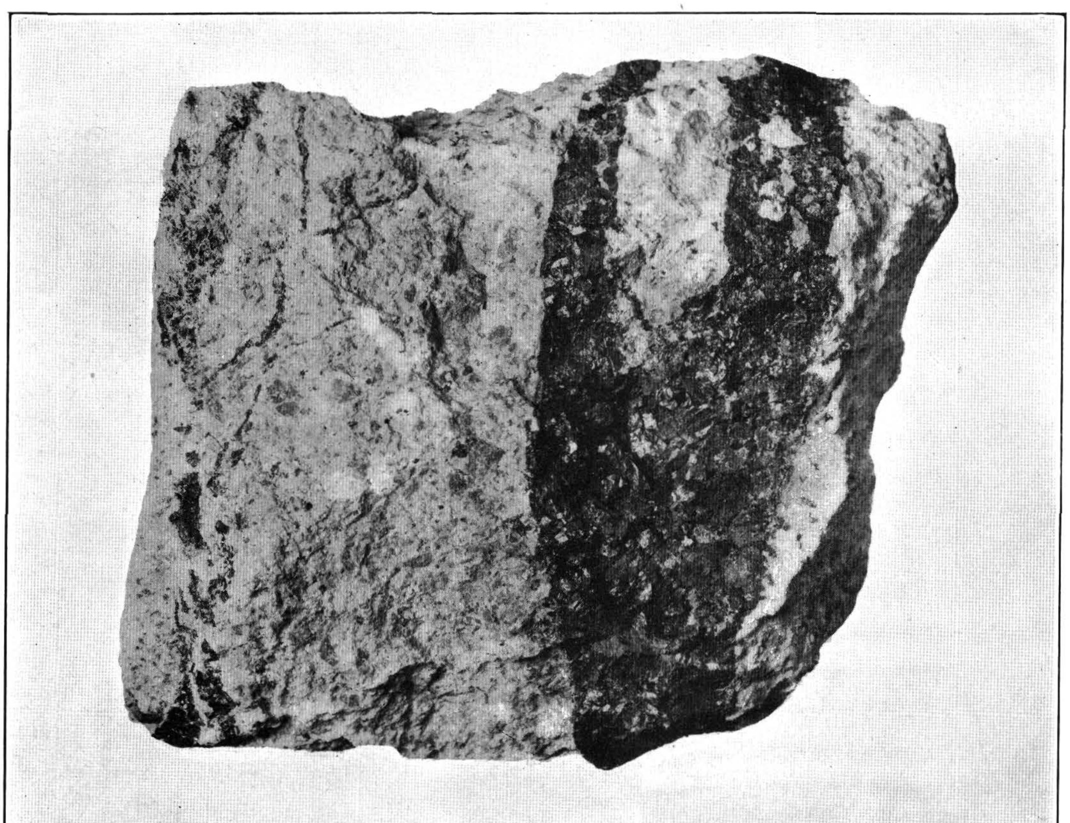
B. VEINLETS OF SIDERITE IN ORE COMPOSED CHIEFLY OF DARK SPHALERITE.
Natural size. See page 87.

ORE FROM WELLINGTON MINE.



A. SPONGY SMITHSONITE IN SPHALERITE, SALLIE BARBER MINE.

Natural size. See page 88.



B. STRINGERS OF SPHALERITE, PYRITE, AND GALENA IN SERICITIZED QUARTZ MONZONITE PORPHYRY, JESSIE MINE.

Natural size. See page 146.

ORE STRUCTURES.

UNDERGROUND DEVELOPMENT.

The plan of underground development of the Wellington mine is shown in Plate XXVIII. The general trend of the veins is N. 37° E. and they have been explored for a total length of 2,600 feet. At the southwest end of the workings is the Oro shaft, with its collar about 50 feet above French Creek. This is connected with four levels at depths successively of 116.5, 185.6, 245.8, and 323.8 feet. A large part of the product from the original Oro mine came from these levels, especially from stopes above the first level, which is about 1,100 feet in length. At present, however, the shaft is filled with water and practically all of the mining is confined to two adit levels. The lower of these, known as the Mill tunnel or Oro level, has its portal near the mill, about 150 feet west of and 5.5 feet lower than the collar of the Oro shaft. This level is a crosscut for 100 feet and thence follows the Siam vein for over 1,900 feet to the northeast, with one important branch to the east on the Orthodox vein. Originally the portal of this level was about 100 feet southwest of the Oro shaft, the level following the Oro vein (see Pl. XXVIII) for about 650 feet and then crosscutting north to the Siam vein. This old drift, although no longer used, is still open, but the crosscut to the north is filled.

About 100 feet above the Oro level is the Extenuate[1] level, the portal of which is 1,600 feet northeast of the portal of the Oro level. Recently an electric tramway has been built between the two adits. The Extenuate level consists of a straight crosscut running 800 feet in a N. 25° 13′ W. direction, with right-hand and left-hand drifts on the principal veins. The upper of these two main levels, which are connected by a few winzes and raises, is only partly superposed over the lower, the lower one extending farther to the southwest and the upper one farther to the northeast. This fact, taken in connection with the absence or present inaccessibility of workings above or below the main levels, confines the study of the mine so nearly to a horizontal plane as to afford little opportunity for working out details of faulting or for observing possible changes in the ore bodies at different depths. About 227 feet above the Extenuate level is the old Wellington tunnel, now abandoned and caved. East of it and about 50 feet lower is the Liberty tunnel, also inaccessible. The Siam tunnel, in the southwest part of the workings, and most of the other shorter tunnels above the Oro level can no longer be entered. The Wellington Mines Co. apparently has no stope maps and its general map is not complete, especially in its representation of disused workings. A large part of the Extenuate level east of the main crosscut could not be examined in 1909 owing to the caving of the drifts or to the presence of foul air.

GEOLOGIC RELATIONS.

The general country rock of the Wellington mine is monzonite porphyry, being part of the same very irregular intrusive sheet that forms the upper part of Bald Mountain. The under surface of this property is not at present exposed in the Wellington workings, but the Oro shaft went into the underlying sediments and the general geologic relations brought out in the mapping of this part of French Gulch, although indicative of much irregularity, suggest that the bottom of the mass as a whole does not lie much below the grade of French Creek. The visible body of porphyry, however, may be connected with dikes that extend indefinitely downward. Just west of the Oro shaft is the mass of quartzite (see Pl. I, in pocket) in which are the Old Union workings. With this the porphyry is in ragged igneous contact. About 450 feet east of the Extenuate tunnel some of the same quartzite, including here, as near the Old Union mine, beds of compact, more or less jasperoidal limestone, is exposed in the lower Brown tunnel. At the Wellington mill is a tunnel that was open in 1908 but has since been closed by the construction of the mill and is not shown on the mine map (Pl. XXVIII). For about 100 feet this tunnel penetrates disturbed decomposed porphyry that is possibly talus. It then enters black shale and continues in this rock for 300 to 400 feet to the face. The bedding of the shale, although more or less disturbed, is on the whole nearly horizontal. No satisfactory information could be obtained in 1908 and 1909 regarding the distribution of rocks found in the Oro

[1] This name as recorded and as used on mine maps is written X. 10. U. 8, a form typographically so inconvenient as to justify the substitution here employed in the text.

shaft and in the levels connected with it. That some porphyry occurs on these levels is known, but they are largely in sedimentary beds. The part of the second level in the vicinity of the shaft, including most of the long northeast crosscut, appears from certain annotations on the company's maps to be in shale. Limestone is noted near the end of this crosscut and porphyry apparently constitutes the rock of the main drift eastward from a point about 25 feet east of the beginning of the northeast crosscut. The third and fourth levels are presumably in shale, or perhaps partly in quartzite, but no definite confirmation of this supposition could be obtained.

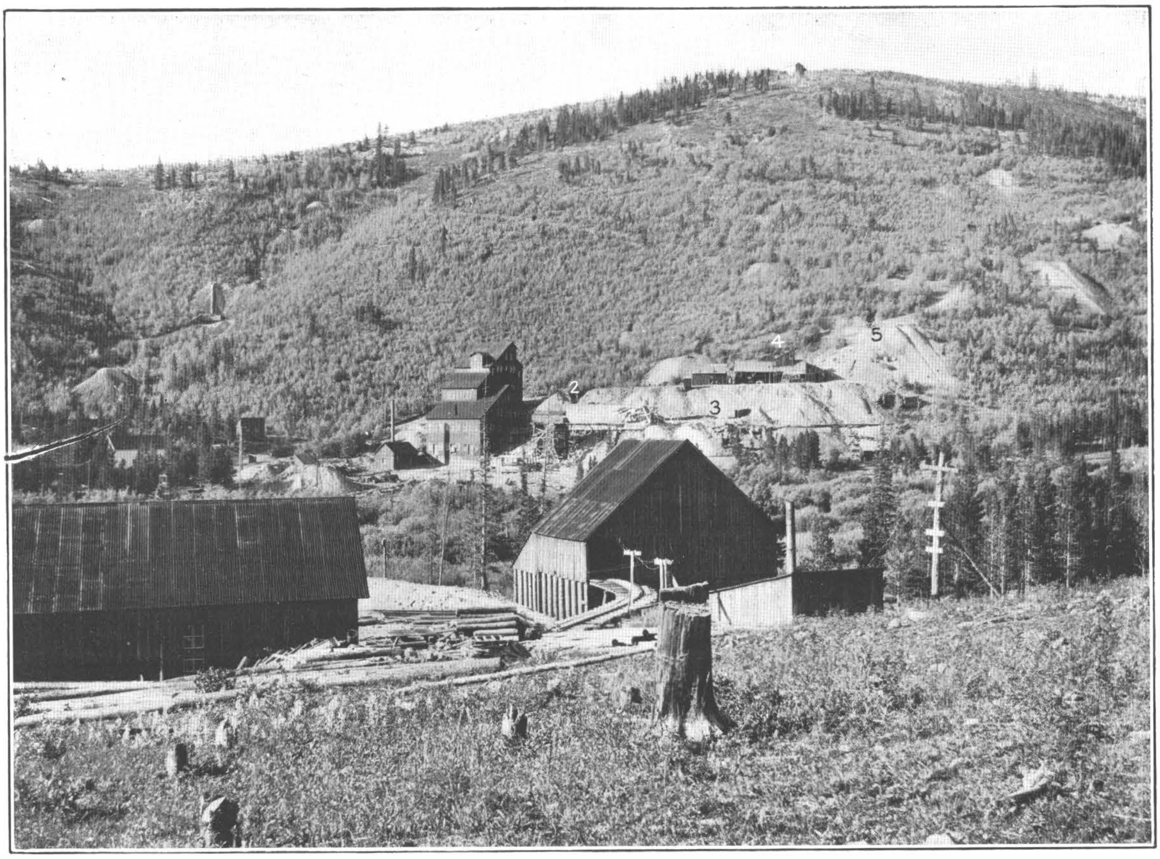
That these various bodies of sedimentary rock may be isolated blocks included in the porphyry is of course a possibility, this suggestion receiving some color of probability from the known occurrence of similar though generally smaller inclusions elsewhere in the district; but the numerous exposures of shale or quartzite, more or less covered by porphyry talus, along the bases of the slopes on both sides of French Gulch (see Pl. I) and the fact that the gravels along this stream are known to rest in many places on the sedimentary rocks indicate that the creek has cut through the main body of the porphyry and that further deepening of the channel would show only relatively small intrusive masses or dikes of the igneous rock.

The prevailing porphyry of the Wellington mine, although apparently a continuous part of the large mass exposed on Mineral and Prospect hills, as well as in the tunnels of the Rose of Breckenridge, Minnie, and Lucky mines, is for the most part an unusually fine grained and inconspicuously porphyritic facies. Chemical analyses of the typical fresh and altered porphyry of the mine accompanied by petrographic descriptions are contained in Chapter III (pp. 43–62). Much of the rock is almost aphanitic in texture, but some of the fresher varieties show abundant small phenocrysts of biotite and are characterized microscopically by the presence of both augite and hypersthene. Such fresh material, however, is exceptional and most of the rock seen in the mine is considerably altered by ore-depositing solutions complicated in many places by subsequent weathering. The nature of these processes of alteration has been described in Chapter VII (pp. 93–102).

As shown on the geologic map (Pl. I, in pocket) the monzonite porphyry of the south slope of Prospect Hill is traversed by a nearly east-west dike of quartz monzonite porphyry. As previously pointed out, the surface exposures of this dike are obscure, and the actual outcrop may not coincide accurately with the mapped outline. The dike may be more variable in width and less continuous along its strike than is represented in Plate I. In the underground workings the quartz monzonite porphyry has been found only in that part of the Extenuate level lying east of the main crosscut and in some of the old, partly accessible workings above this part of the level. As is shown in figure 12, the principal body of the quartzose porphyry is exposed at that part of the level where the Siam and Iron veins approach each other under the old Wellington tunnel. The relations of this mass, which may be seen to be of irregular plan with little to suggest dikelike continuity, are obscure. In some places it is in igneous contact with the monzonite porphyry, but in most places the two rocks are separated by fissures having slickensided walls and containing varying quantities of gouge and ore. The mass appears to represent an originally irregular dike that has been modified in shape by faulting. In the now inaccessible east drifts the dike is said to be more regular, although it is cut into segments that are offset by north-south faults. Whether the quartz monzonite porphyry exposed at the face of the main Extenuate crosscut (see fig. 12) is continuous with the body just described is not known. The Iron vein on the Extenuate level is in quartz monzonite porphyry. About 100 feet above the level the hanging wall of the vein is monzonite porphyry, and about 90 feet above this the whole vein, for the short distance along which it could be examined in 1909, is in the monzonite porphyry. No quartz monzonite porphyry had been found on the Oro level at the time of visit.

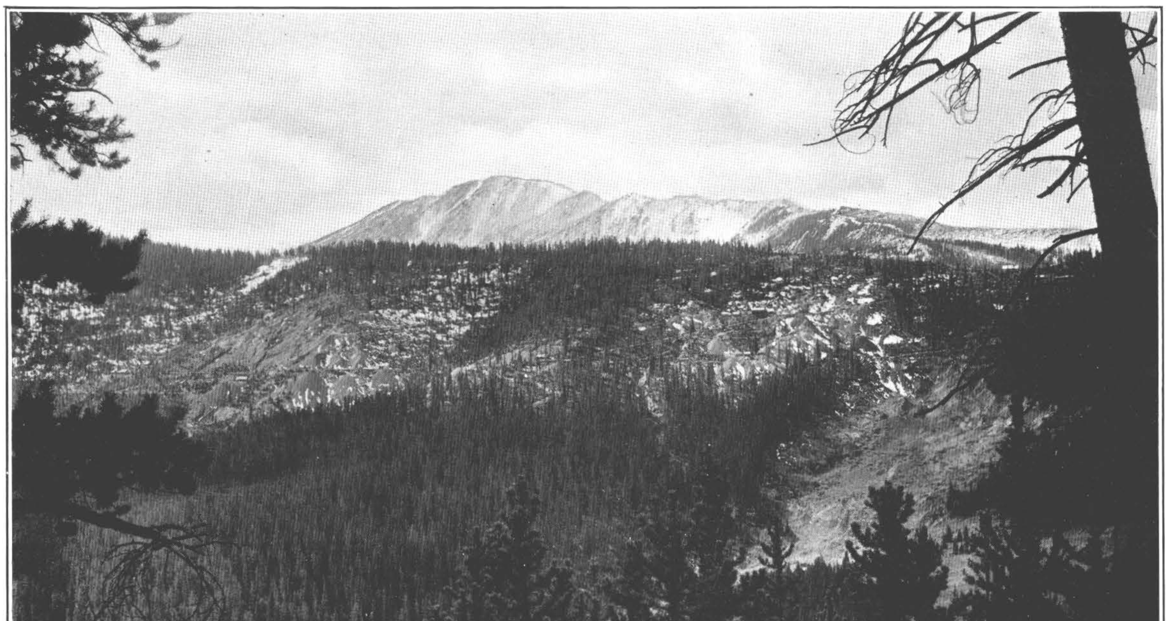
ATTITUDES AND GROUPING OF THE VEINS.

The veins worked in the Wellington mine are members of a linear system that extends in a general N. 37° E. direction diagonally over the southeast slope of Prospect Hill from a point in the bed of French Creek, northwest of the mouth of Nigger Gulch, to the west side of Lincoln Park, on the northwest side of Mineral Hill. Other mines and prospects on the same group of



A. WELLINGTON MINE FROM THE LOWER COUNTRY BOY TUNNEL.

These are properly the Oro workings, the old Wellington tunnel being nearly half a mile up the gulch, to the right. The course of the vein is diagonally up the hill to the right, nearly along the line of dumps. There is no real outcrop. 1. Mill. 2. Main Oro adit. 3. Old Oro adit. 4. Oro shaft. 5. Siam tunnel. See page 126.



B. FARNCOMB HILL FROM THE NORTH.

The steep ridge in the distance is Bald Mountain, separated from Farncomb Hill by French Gulch. The productive part of the hill, as regards the rich gold veins, extends from the Ontario shaft house, just visible on the crest to the right, diagonally down the hill to Dry Gulch, which is the small ravine on the extreme left. The first group of dumps east of the Ontario marks the workings of the Key West and Boss mines. In the larger area to the east of these, denuded of trees and covered with dumps, are the workings of the Wapiti group. Below the Ontario and Key West may be seen the old placer workings at the head of Georgia Gulch. See page 153.

veins are the Old Union, Mono, Minnie, Cincinnati, Lucky, Ella, Truax, and Melbourne. That at least one vein of the group underlies the gravels of French Creek has been shown by masses of sphalerite scooped from the bedrock by the Reliance dredge. What becomes of the belt south of the creek, toward Nigger Hill, is not known. Exposures in this direction are poor, and although numerous fissures traverse the quartzite of Nigger Hill, their identity with the Wellington fissure zone is by no means clear. Knowledge of the northeast end of the zone is likewise meager, the workings of the Melbourne shaft, which might throw some light on this question, being unfortunately inaccessible. The known length of this chain of fissures is about 1¾ miles, and its greatest width is probably between 1,000 and 1,500 feet.

No one fissure is continuous for the whole length of the zone. Owing to lack of outcrop and to the disconnected character of the workings, many of which are unmapped and can no longer be entered, it is impossible to present a plan of the veins as a whole or to describe their relations to one another in any but general terms. It is reasonably clear, however, that the belt was made up originally of a dominant set of nearly parallel fissures, each fairly regular along its middle portion but pinching out or splitting up in various irregular ways at its ends. Crossing these parallel fissures are some important east-west fissures. The prevailing dip of the principal veins is southeast or south at angles ranging from 45° to 90°. The most common or average dip is about 65°.

In the Wellington mine the principal veins recognized are the Oro, Siam, Orthodox, Spur, Iron, and East veins. The Oro vein has been followed underground from the vicinity of the Oro shaft for a distance of about 600 feet to the northeast. As may be seen from figure 12, it is not a simple steeply inclined sheet of ore and gangue but divides into several branches and is offset by cross faults. The details of these complications can not be satisfactorily worked out from existing exposures, but it appears probable that the Oro vein is not really distinct from the Siam vein but is linked to the latter by ore-bearing fissures. In the old Oro level (see fig. 12) the Oro vein is cut off about 550 feet northeast of the shaft by a fault fissure that strikes about N. 47° E. and dips 60° NW. The fissure, which is generally about a foot wide, is filled with soft crushed porphyry containing a

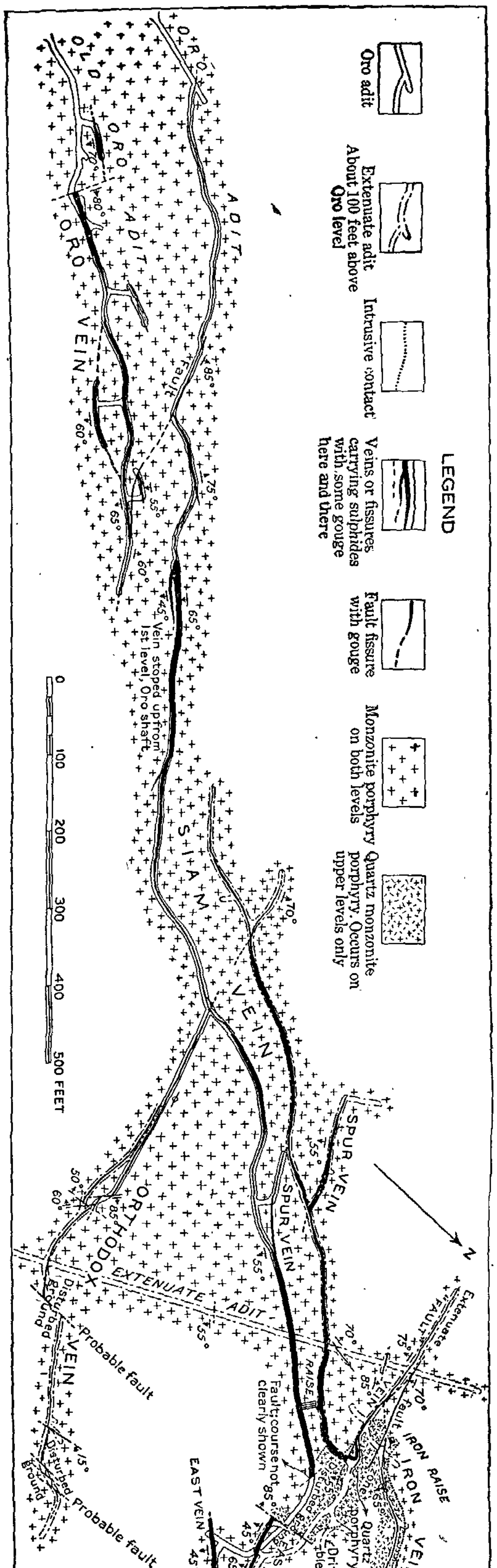


FIGURE 12.—Geologic plan of the Oro and Extenuate levels of the Wellington mine.

little broken sphalerite. The fault movement is apparently normal and offsets what is supposed to be the northeast continuation of the Oro vein about 75 feet to the southwest. Between this old Oro level and the newer workings on the Siam vein at about the same level there are no open drifts or crosscuts, and it is impossible to offer more than the suggestion that the Oro vein is merely one or more of the branches into which the Siam vein splits as it is followed to the southwest. This view is supported by the fact that some of the old stopes worked from the Oro shaft were carried up on the Siam vein and connect with the present Oro adit. (See fig. 12.)

The present main adit or Mill tunnel is a crosscut for about 100 feet and then for 450 feet in a general northeast direction follows a rather devious fissure zone containing a few stringers of sphalerite and some seams of gouge, but no ore. The general dip of the fissures along this part of the drift is to the northwest at angles up to 85°, the inclination being opposite in direction to the normal dip of the Siam vein.

At the end of the 450-foot stretch of barren fissuring the drift reaches an ore body and, leaving the fissures hitherto followed (see fig. 12), turns sharply from a course of about N. 70° E. to one of N. 35° E., which is the local strike of the ore. The dip of this ore is 75° NE., and it evidently is not the main Siam vein, although it probably joins that vein above this level. On the level a few unimportant stringers lead about N. 70° E. for 75 feet into the Siam vein, which is wide at this point and dips 65° SE. The breaks in the continuity of the ore just described are apparently not an effect of faulting after the ore was deposited, although seams of gouge testify to some such late movement as a minor feature of the structure. They are due essentially to the fact that the fissuring had originally a branching character, the spurs showing wide divergence both in strike and dip from the general attitude of the fissure zone as a whole or of its most persistent members.

The main Siam vein, from the point where it is first entered by the Mill tunnel to a point under the Wellington tunnel (see Pl. XXVIII), has been followed continuously for a distance of over 1,200 feet. Its course, however, is far from straight and the fissuring is not everywhere accompanied by ore. Here and there subordinate fissures or spurs make off into the walls of the drift. Two of these branch veins, known as the Orthodox vein and the Spur vein, are important and contain some ore.

The Orthodox vein, which branches from the Siam vein to the east and possibly to the west also, is practically vertical. Its course near the Siam is N. 75° E., but east of the Extenuate tunnel it strikes generally N. 50° E. and is displaced by faults, as indicated in figure 12. On the Oro level the Orthodox vein is not known to cross the Siam vein. On the Extenuate level, however, 100 feet above the Oro, a spur vein lying in the general course of the Orthodox has been followed for a short distance west of the Siam vein. It consists of a few irregular stringers with no ore in commercial quantity and has a general dip of about 70° N. It is probably the Orthodox vein.

About 300 feet northeast of the junction of the Orthodox and Siam veins is a short west branch from the Siam, known as the Spur vein. This dips 60° S. and carries a good body of ore on the Extenuate level. Although the Spur vein is in places 8 feet wide it pinches and becomes very small about 150 feet west of the Siam vein. It has not been explored immediately east of the Siam vein and no indication of an important vein was noted in that wall of the drift. A line of fissuring may, however, extend through to what is known as the East vein. (See fig. 12.)

Northeast of the Spur vein the Siam vein maintains its regular course and is continuously ore bearing on both levels for a distance of about 350 feet. In the vicinity of the Wellington tunnel, however, the vein terminates abruptly at an east-west zone of disturbance known in part as the Fault vein. On the Extenuate level this ending occurs in quartz monzonite porphyry. (See fig. 12.)

The so-called Fault vein consists of one or more strong seams of gouge accompanied by a little ore or sulphides and by much polishing and grooving of the wall rock. In some places the zone of slipping and fracturing is from 30 to 40 feet wide and on this account it is difficult

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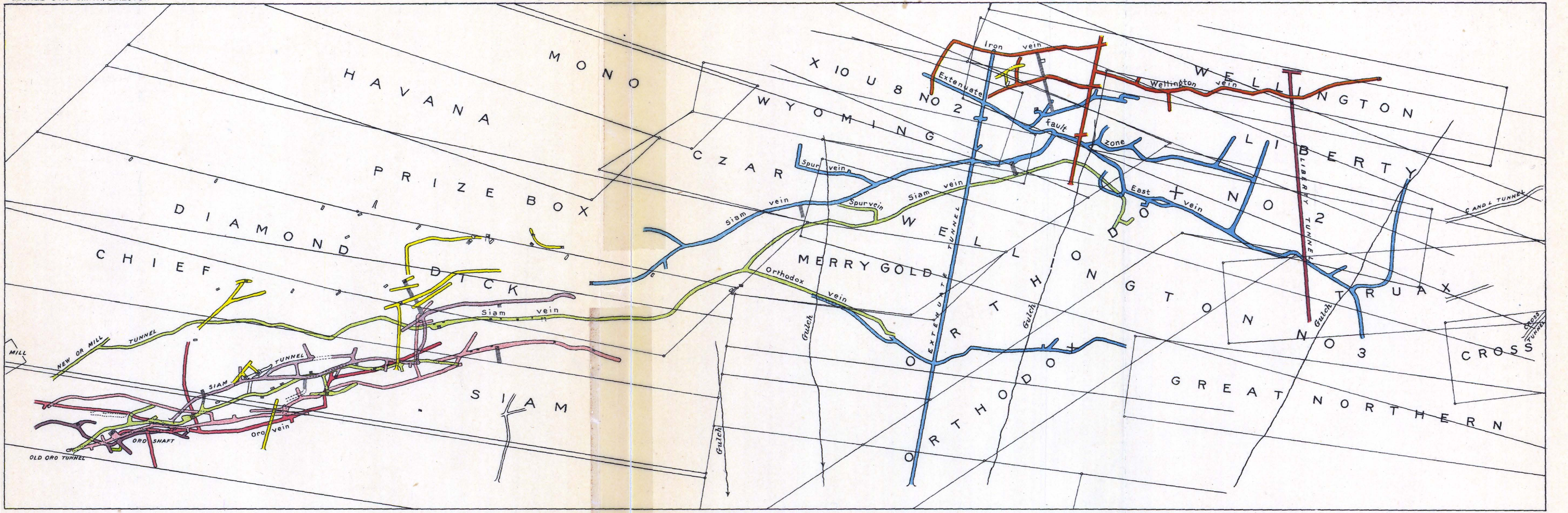
PROFESSIONAL PAPER 75 PLATE XXVIII



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GENERAL PLAN OF THE PRINCIPAL UNDERGROUND WORKINGS OF THE WELLINGTON MINE

0 100 200 300 400 500 600 FEET

Old superficial workings (mostly closed)

Wellington tunnel (caved), about 327 feet above Oro level

Liberty tunnel (caved) about 275 feet above Oro level

Siam tunnel (caved) about 50 feet above Oro level

Extenuate (X. 10. U. 8.) level, about 100 feet above Oro level

Oro level

First or 116-foot level, Oro shaft (under water)

Second or 185-foot level, Oro shaft (under water)

Third or 246-foot level, Oro shaft (under water)

Fourth or 324-foot level, Oro shaft (under water) without more extensive exposures than are now available to outline accurately its course and dip. It appears to run in general about N. 65° to 75° E., or very nearly parallel with the Orthodox vein, and dips to the south at angles of 55° to 75°.

North of the Fault vein and about 50 feet northwest of the point where the Siam vein would be if it maintained its original course, is the Iron vein. This strikes in general northeast and dips 65° SE. It is thus nearly parallel with the Siam vein and a glance at figure 12 suggests that it is nothing more nor less than an offset part of the Siam vein. The Iron vein was extensively stoped above the Extenuate level and westward to the fault, but it contains no ore to speak of on that level, where it is nearly all in quartz monzonite porphyry.

There is said to be another vein, the Wellington, lying from 50 to 75 feet southeast of the Iron vein in the old Wellington workings. This, however, has not been definitely recognized on the Extenuate level and nothing could be seen of it in 1909. It may be merely a branch of the Iron vein.

The East vein, as its name implies, lies east of the northeast end of the Siam vein, but apparently south of the Fault vein. Its general course as exposed along a distance of about 200 feet on the Extenuate level is N. 75° E., or nearly parallel with the Fault vein. Its dip varies from 45° to 65°, and this accounts for the change in direction of the vein between the Oro and Extenuate levels, as shown in figure 12. Although the East vein has been regarded by some as a faulted portion of the Siam vein, this is not probable. It is more likely to be a part of the Spur vein.

FAULTING.

The veins of the Wellington group have been affected by at least two chronologically distinct sets of faults. The principal fissures of the older group strike nearly east and west and are most conspicuously exemplified by the Fault vein; those of the younger group run nearly north and south and are best seen in the workings on the East vein. There are also some minor displacements by fissures having various trends and not clearly belonging to either of the above groups.

The Fault vein of the miners, or, as it may better be designated, the Extenuate fault zone, is visible on the Oro level, on the Extenuate level, and in the part of the old Wellington workings reached through the Iron raise (fig. 12). On the Oro level, owing mainly to the necessity for close lagging of the broken ground, no structural details can be made out. The Siam vein comes to an abrupt end and the drift continues for some distance through soft shattered porphyry, whence it emerges as it curves southeast to the East vein. On the Extenuate level the conditions for observation are more favorable. About 50 feet before reaching the fault the Siam vein bends westward and quartz monzonite porphyry appears in the hanging wall, as shown in figure 12. Thirty feet farther on both walls are composed of the silicic porphyry, which apparently was offset about this distance by the faulting that attended the opening of the vein. A few feet farther on the vein is slightly offset by what appears to be a branch fissure of the main fault zone. The ore here shows brecciation and at the junction of the drifts it is crushed, bent to the west, and tails off as dragged ore along one of the fissures of the Extenuate fault zone. The bend in the Siam vein near the fault and the direction in which the ore is dragged both indicate that the continuation of the Siam north of the fault has been displaced to the west.

Most or all of the small faults noted in the mine are apparently of the normal type and the Extenuate fault zone is probably also one in which the hanging walls of the fissures have moved downward relatively to the foot walls. Inasmuch as the Siam vein dips to the southeast and the fissures of the Extenuate fault zone dip to the south, normal faulting with movement straight up or down the dip would offset the northeastern continuation of the Siam vein to the hanging-wall or east side. The movement in this case, however, was not up or down, but along lines corresponding more nearly to the strike of the fault.

The walls of the gouge-filled fissures of the Extenuate fault zone are in many places beautifully polished and are marked by grooves or striations which pitch to the east at angles ranging from 10°, or less, to about 45°.[1] Evidently displacement had a large horizontal component. The hanging wall slipped east much more than it slipped down, and consequently the part of the Siam vein north of the fault has probably been offset to the west instead of the east; in other words, it would have the relative position of the Iron vein, which is regarded as being the continuation of the Siam vein north of the fault. It corresponds closely to the Siam vein in dip and strike, is cut off at its southwest end by the same fault zone, lies in the proper position, and above the Extenuate level, where it is nearly barren, shows mineralization similar in importance and kind to that of the Siam vein. The maximum net movement along the fault zone can not be determined accurately owing to the curvature of faults and veins. If, however, the dip of the fault zone and of the veins is taken at 65° and the pitch of the direction of principal movement (that is, the angle between the striations and a horizontal line, measured in the plane of the fissure) is taken as 15°, then the total net slip between the walls necessary to effect the present offset between the Siam and Iron veins would be from 150 to 170 feet. If the movement was more nearly vertical than would accord with striations having an average pitch of 15°, then the total net slip must have been greater. It may be of interest to note that had the movement been such as to grave striæ pitching about 80° E., then it would not have perceptibly offset the vein, as this is approximately the angle of pitch of the trace of the Siam vein on an ideal fault plane with a 65° dip to the south.

The displacement apparently was not confined to a single fissure and the details are not satisfactorily exposed in the workings now accessible. A strong gouge-filled fissure passes obliquely through the Iron vein at the raise shown in figure 12. This, however, does not appear to be the place of principal movement, for the Iron vein is said to continue southwest past this raise to a point within 50 feet or so of the main Extenuate crosscut. Here it is definitely cut off. Such parts of the old stopes as are accessible through the Iron raise also show the vein to continue for some distance past the raise, although it is cut by a number of gouge-filled fissures that cross it at small angles. Between the Iron raise and the end of the Siam vein on the Extenuate level intervenes about 30 feet of fissured and disturbed quartz monzonite porphyry, which is probably within the fault zone.

By climbing about 100 feet up the Iron raise it was possible in 1909 to penetrate southwest through the old stopes on the Iron vein to the Extenuate fault zone, where the vein abuts sharply but obliquely against a strong seam of gouge. At this place the Iron vein strikes northeast and dips 65° SE. The principal gouge seam strikes N. 65° E. and dips southeast at the same angle as the vein. The zone of gouge and crushed porphyry exposed at this point is fully 10 feet wide.

The Extenuate fault zone is not altogether younger than the Siam vein. Along it in places are stringers of sulphides and ore enough to have encouraged considerable prospecting. Some of the ore was undoubtedly dragged in from the Siam vein, but some appears to have been originally deposited along the fissures. It is probable that the fault zone was in the first place an east-west cross vein like the Orthodox and was formed and filled at about the same time as the Siam vein. Later stresses transformed this vein into the Extenuate fault zone and separated what is known as the Iron vein from the Siam vein, with which it was once directly continuous.

A series of north-south faults younger than the Extenuate fault zone have further complicated the structure of the northeastern part of the mine. One of the best exposed of these is the fault that cuts off the East vein at its west end on the Extenuate level. This fissure dips 85° W. and contains from 1 to 2 feet of crushed porphyry and soft gouge lying between slickensided walls with nearly vertical striæ. The hanging wall, not well exposed, is probably quartz monzonite porphyry; the footwall is monzonite porphyry. This may be the same fissure that displaces the Orthodox vein just east of the main adit crosscut, but lagging at this place conceals the course of the chief disturbing fissure.

[1] Since the observations on which this description is based were made, Mr. John Wellington Finch has completed a careful structural study of the mine, and his report, which he very kindly sent to me, has helped materially to clear up some doubtful points regarding the relation between the Siam and Iron veins Mr. Finch distinguishes two sets of these striations—an older set pitching at angles from 10° to 20° and a younger set pitching from 40° to 50°. If he is correct in this it is possible that close observation might somewhere detect traces of the older grooves directly crossed by the younger.—F. L. R.

About 100 feet east of the cross fault just described the East vein suffers a second dislocation, as shown in figure 12. This fault fissure is not well exposed but apparently dips 60° E.[1] A number of other north-south faults are reported also in the generally inaccessible workings east of those shown in figure 12.

West of the Extenuate tunnel the Orthodox vein, although crossed by a few faults of small displacement, is fairly regular. East of the tunnel, however, the entire drift supposed to be on the Orthodox vein is in soft, very much disturbed rock in which the vein can be followed only as a series of crushed fragments. The numerous gouge-filled slips for the most part show no regularity in arrangement or direction and appear to have little individual persistency; but better exposures would probably show the vein to be cut by north-south faults much as is the East vein. Doubtless some of these fissures continue through from one vein to the other. At about 200 feet from the Extenuate tunnel the vein is displaced by a strong gouge-filled fissure with a dip to the east of only 15°. The general disturbance in the neighborhood of this fault, however, is so great as to obscure its effect on the vein and the direction and character of the displacement were not ascertained.

Several faults of small to moderate displacement are exposed in the old Oro tunnel in the western part of the mine. The most important of these has already been described on page 129.

The movement along the north-south faults was probably accompanied by some renewal of movement along the east-west faults. It is to this later movement that Mr. Finch ascribes the steeper set of striæ noted by him on the walls of the Extenuate fault zone.

CHARACTER AND MATERIALS OF THE VEINS.

The veins of the Wellington mine attain a maximum width of about 15 feet, most of the stopes ranging from 4 to 10 feet. Those over 8 feet wide generally include one or more slabs or horses of country rock. The vein material is composed essentially of pyrite, sphalerite, and galena in various proportions with relatively little gangue. Such waste as occurs within the ore bodies consists as a rule of horses or small fragments of metallized porphyry or of pyrite containing too small a proportion of galena and sphalerite to be classed as ore. True gangue, where present, is siderite or barite. These minerals, however, are nowhere abundant and are younger than the sulphides, in which they occur as veinlets or as the lining of vugs.

Metasomatic replacement has played an important part in the formation of the veins, but the process, so far as relates to commercial ore bodies, has been confined to fissured or crushed rock. Consequently the ores do not extend irregularly into the country rock on each side of the vein, but lie as a rule between fairly well-defined walls, which correspond closely to the original boundaries of the main fissures. Fragments of porphyry within the fissure zone, especially if of small size or traversed by many cracks, have been more or less changed to ore, partly by the filling of interstices and open spaces, partly by replacement. The ore is generally solid and firm and is accompanied by no persistent gouge along either wall. Locally gouge may be present between walls and ore, and the ore bodies in a few places are traversed by fissures filled with crushed ore or gouge. In the vicinity of faults, also, the ore is fissured and broken.

Although the vein material is generally firm, it is not entirely solid, small interstitial spaces between the crystals, or vugs, some of them incrusted with siderite or barite, being so abundant as to give the whole a porous texture. The constituent sulphides are not arranged in any general order, and the ore affords little more than a suggestion of original banding here and there. The prevailing texture is that of a granular aggregate of galena, sphalerite, and pyrite, the three being combined in different proportions in different places and showing much variation in coarseness of crystallization. Crystals of galena attain the largest size, some of them being 2 inches across. This, however, is exceptional.

A very characteristic feature of the Wellington ore is the manner in which it is traversed by white or pale buff veinlets of carbonates approximating to siderite in composition. In some

[1] This fault, according to Mr. Finch, has been cut also on the Oro level in the east drift on the East vein, extended since my own visits to the mine.—F. L. R.

parts of the veins these veinlets, most of which are less than an inch in width and are inclined to be vuggy along their middle planes, are arranged parallel with the walls of the main vein, giving the ore a banded appearance. In other places the carbonate veinlets branch irregularly through the sulphides in all directions, and in a few places the sulphides have been brecciated and the fragments are now cemented by the sideritic carbonate. The carbonate veinlets are distinctly later than the principal epoch of sulphide deposition and as a rule contain no sulphides except in the form of included fragments. The siderite is present in some form in nearly all of the ore, either as the veinlets just described or as the lining or filling of small interstices in the original porous bodies of sulphides.

The tenor of the Wellington ore varies widely, some being essentially a lead-silver ore and some essentially a zinc ore. A typical technical analysis of the crude shipping ore is given in the table on page 108. Another variety of the ore, such as that in the east face of the Oro level in 1909, carries 38 per cent of zinc with only 1 per cent of lead. Technical analyses of the first-class concentrates and of carbonate ore from surface workings on the Wellington ground are also given on page 108.

OXIDATION OF THE ORE.

Even along the outcrops of the veins most of the shafts and tunnels show some galena in the claylike product resulting from thorough oxidation, and the change to essentially sulphide ore generally takes place at depths of less than 300 feet. The depth of the oxidized zone, however, varies, being greatest in general near the crest of the ridge in which the ore bodies occur and least along the lower slopes. On the main levels of the Wellington mine the ore as a rule shows no oxidation, although in a few places there has been a slight development of smithsonite in interstices of sphaleritic ore. Owing to the inaccessibility of the old upper workings there is little opportunity at present for studying the transition from partly oxidized ore to sulphide ore. The normal sequence, however, from the surface down, appears to be (1) a soft, heavy, yellowish clay-like ore consisting largely of earthy cerusite and containing residual nodules of galena; (2) a lead-silver ore in which the galena is only in part oxidized, while the pyrite has been for the most part changed to limonite and the sphalerite altered to smithsonite and limonite, with removal of much of the zinc in solution; and finally (3) a lead-silver-zinc ore in which galena predominates and in which the early stages of oxidation are indicated by the formation of a little spongy smithsonite, or "drybone," as the miners call it, at the expense of the zinc blende.

COUNTRY BOY MINE.

INTRODUCTION.

The Country Boy mine is about a quarter of a mile south of the Wellington, on the opposite side of French Creek. It has been intermittently productive since about 1889, first of a silver-lead ore carrying some gold and afterward of a high-grade zinc ore. The property has long been in litigation and consequently its development has been neither steady nor systematic. In 1907 the mine is reported to have yielded 76 cars of ore carrying from 47 to 55 per cent of zinc. It was idle in 1908 but was being worked again in 1909, producing a zinc ore that was shipped as it came from the stopes. Very little development work, however, was in progress.

UNDERGROUND WORKINGS.

It was found impossible to procure any complete map of the Country Boy mine, but a general plan and section of a part of the underground workings of the mine are shown in figure 13. There are two adits 170 feet apart vertically and not connected. The upper tunnel runs about S. 18° E. for 700 feet and then, turning slightly, continues for 1,000 feet in a S. 25° E. direction. This tunnel cuts the Country Boy vein between 400 and 450 feet from the portal, and is connected with old drifts and stopes on this vein, now only in small part accessible. About 350 feet beyond the Country Boy vein the tunnel cuts the Hite vein, which was being prospected in 1909 by a winze. The lower tunnel runs southeast for 1,050 feet to the Country Boy vein, where it connects with short drifts and with stopes about 250 feet in total length and 90 feet high at the time of visit.

GEOLOGIC RELATIONS.

The rocks are poorly exposed in the vicinity of the mine. The principal rock of Nigger Hill is monzonite porphyry, which is part of the same great irregular sill that forms the crest of Bald Mountain. Both east and west of the Country Boy mine this porphyry comes down to the bottom of French Gulch. (See Pl. I, in pocket.) In the immediate vicinity of the mine, however, is a triangular area of black shale and quartzite inclosing an oval area of monzonite porphyry. Presumably the shale overlies the quartzite, and both are cut by the porphyry, but these relations are not evident from what may be seen at the surface. Another possibility, which could not be verified, is that the vein occupies a fault fissure which at the surface separates quartzite on the southeast from porphyry and shale on the northwest.

The upper tunnel, at an elevation of 10,100 feet, enters the hillside in the oval area of porphyry and continues in this rock for 250 feet. It then goes through black shale for 37 feet, but as both rocks are here greatly disturbed it is impossible to say what their stuctural relations are at this place. Porphyry, with a few masses of much-broken black shale, continues to the Country Boy vein, 450 feet from the portal. Beyond the vein the tunnel passes through a little shattered quartzite, of which the stratigraphic relations are very obscure, into gray shale that dips about 15° N. and apparently underlies the quartzite. At a distance of 600 feet from the

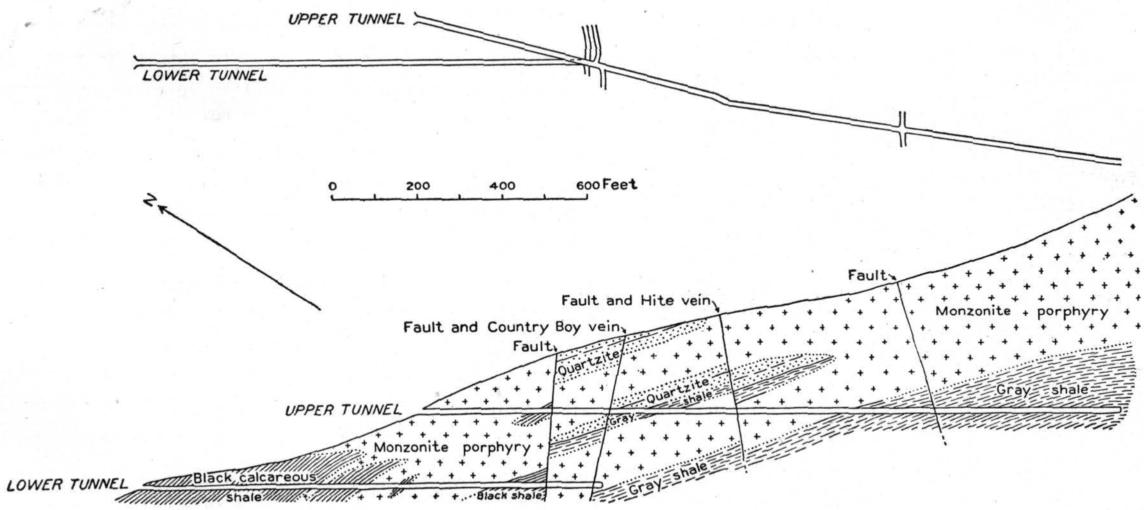


FIGURE 13.—Plan and section of the Country Boy mine. Only a part of workings shown. Geologic section is largely hypothetical.

portal the tunnel passes from this shale into the upper part of a porphyry sill which it traverses for about 425 feet. Both upper and lower surfaces of the sill, where cut by the tunnel, are regular and conform to the bedding, which dips 17° NNW. These relations indicate an actual thickness of about 100 feet for the intrusive sheet. There is no appreciable contact metamorphism of the beds.

After emerging from the under side of this sill, which is probably connected directly with the irregular sheet of porphyry forming the upper parts of Nigger Hill and Bald Mountain, the tunnel continues for nearly 700 feet in greenish-gray calcareous shale. This dips generally 17° NNW. but at the face has a dip to the east of only 5°. The shale is cut by four or five faults of small to moderate displacement. They strike generally from northeast to north-northeast and dip southeast. The throw for the smaller faults, amounting in one fault to 18 inches, is normal, and probably all are of this type.

The stratigraphic position of this gray shale is not entirely clear. It is thought to underlie the Dakota or to be a basal phase of that formation.

The lower tunnel, at an elevation of about 9,930 feet, goes through black calcareous Upper Cretaceous shale for about 500 feet. Near the portal this strikes N. 60° W. and dips 25° NE. Near the 500-foot point it strikes N. 85° W. and dips 50° N. One small sill of porphyry occurs in this shale about 450 feet from the portal. For about 300 feet beyond this shale the tunnel goes through a porphyry sill which is cut by some faults and contains a small mass of black shale apparently faulted in. Beyond and under the sill is more black calcareous shale striking N. 60° to 70° W. and dipping from 30° to 45° NE. The tunnel traverses this shale for 125 feet and then passes through a fault fissure into diorite porphyry, which contains the Country Boy vein on this level. The fault strikes N. 10° E., is practically vertical, and probably belongs to the same class as the north-south faults of the Wellington mine.

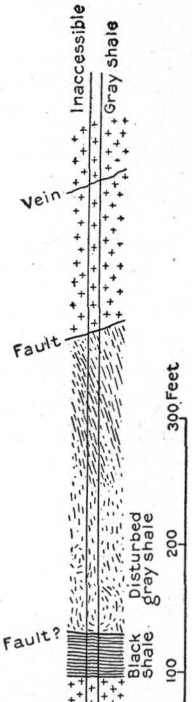


FIGURE 14.—Geologic section through the Helen tunnel.

The ascertained facts regarding the geology of the Country Boy mine and a tentative interpretation of the structure are shown in figure 13. The data obtainable, however, are so meager and unsatisfactory that the diagram is rather a suggestion of possibilities than a representation of known relations. It is not intended for an accurate section through the mine.

VEINS.

The Country Boy vein, owing to the condition of the old workings, could be studied in 1909 only in the stopes above the lower tunnel. Its general strike is approximately northeast and it dips northwest, apparently at an average angle of about 80°. The part of the vein examined is entirely in monzonite porphyry and attains a maximum width of about 5 feet.

The best ore consists of rather friable dark sphalerite with practically no gangue except a fine granular sideritic carbonate that is younger than most of the sphalerite and fills fissures and interstices in the ore. At the time of visit the stope was about 250 feet long and at the ends showed a gradation from the high-grade sphaleritic ore into material containing abundant pyrite. Galena is rare in this stope and occurs only in small bunches up to the size of a man's fist.

Some of the sphalerite occupies clean-cut fissures in the porphyry, but most of the ore appears to have filled interstices and replaced crushed porphyry in a zone of fissuring and brecciation. While the boundary between ore and country rock is generally definite, the neighboring porphyry shows considerable metasomatic alteration and contains pyrite and sphalerite in veinlets and in disseminated crystals.

The ore has not been much disturbed since its original deposition, but there appears to have been some movement along the plane of the vein after the sulphides were formed, and where the ore pinches the course of the vein is marked by a seam of tough gouge. It is by no means certain, however, that this gouge is entirely younger than the ore.

The unsorted ore as mined in 1909 was said to carry from 42 to 43 per cent of zinc. No attempt was being made to work milling ore.

HELEN MINE.

The Helen mine lies on the south side of French Gulch between the Country Boy mine and the mouth of Australia Gulch. The old workings, principally a tunnel that enters in the quartzite spur just west of Australia Gulch (see Pl. I, in pocket), are closed by caving. Recently a lower tunnel has been run from a point 800 feet northwest of the old tunnel and 200 feet lower. The new tunnel has a course of S. 20° E. and is about 927 feet long. It was examined during the preliminary visit to the district in 1908, but in 1909 work had been abandoned and the tunnel was blocked by a fall of shale.

The geologic section afforded by the Helen tunnel is similar to that of the Country Boy Tunnels and is shown in figure 14. Shales, including Upper Cretaceous shale and gray calcareous shale of the Dakota, have been intruded by sills and dikes of diorite porphyry and all the rocks have been subsequently faulted.

The vein, which is cut at about 875 feet from the portal of the tunnel, strikes N. 60° E. and dips about 65° SE. The walls, so far as exposed in the workings, are monzonite porphyry. The vein material is very similar to that of the Country Boy, but the stringers of sphalerite thus far opened in the Helen tunnel are too small to mine with profit.

SALLIE BARBER MINE.

The Sallie Barber mine is situated on the steep spur east of Australia Gulch and south of French Creek. It is worked through a shaft 365 feet deep, with levels at 240, 300, and 350 feet. The lowest level at the time of visit was about 100 feet long, and neither of the upper levels exceeds 300 feet in length. The mine is accordingly a small one and has no great production to its credit.

The Sallie Barber vein strikes N. 54° E. and dips 80° NW. It is entirely in monzonite porphyry and is a fairly regular zone of crushed metallized rock, in places 9 feet wide. The strike of the vein carries it obliquely across the Sallie Barber claim for about 600 feet, the ground beyond, on both sides, being part of the Little Sallie Barber property.

The ore, consisting of sphalerite and pyrite, much of it very friable, occurs partly in bunches and stringers filling original spaces in the fissure zone but mainly as a metasomatic replacement of crushed porphyry. The vein contains comparatively little gangue. The most abundant mineral of this class is a sideritic carbonate, which, as in the Wellington and Country Boy mines, is younger than most of the sphalerite and pyrite. Its deposition was accompanied, however, by the formation of considerable younger pyrite and of a little sphalerite, the latter being rosin-colored whereas the older sphalerite is nearly black.

Oxidation of the pyrite extends to a depth of 250 feet. From the surface down to 200 feet no ore of consequence was found. Below that and above the 240-foot level was stoped a lead ore consisting of cerusite with some residual galena. This ore was found to change downward into the present zinc ore, which is practically free from galena. The ore on the bottom level is not entirely free from oxidation, as is shown by the occurrence of some impure smithsonite with the sphalerite. The alteration results in a porous structure, space formerly filled by sphalerite or perhaps by gangue carbonates being now occupied by spongy masses of smithsonite, as shown in Plate XXVI, *A* (p. 126). The pyrite in the ore is unattacked at this stage of alteration; indeed, some small crystals of pyrite have been deposited with the smithsonite.

It appears probable that acid sulphate solutions from the overlying zone of general oxidation attacked simultaneously the sphalerite and the bunches of dolomitic gangue in the ore, setting free carbonic acid, which reacted with some of the zinc sulphate to form smithsonite.

The ore from the Sallie Barber mine is sorted to a product containing from 30 to 35 per cent of zinc and is shipped to the Western Chemical Co. at Denver.

LITTLE SALLIE BARBER MINE.

The Little Sallie Barber shaft is about 300 feet northeast of the Sallie Barber and is 300 feet deep, with short levels at 200, 250, and 300 feet on what is apparently the Sallie Barber vein. Up to the time of visit in 1909 less ore had been found in this part of the vein than in the neighboring mine, and no shipments had been made A considerable part of the lode in the Little Sallie Barber is a zone of soft crushed porphyry, containing only small bunches of sulphides. Some galena was found on the 200-foot and 250-foot levels, but this mineral has not been seen on the 300-foot level. Some of the ore shows veinlets and crusts of white calcite that are younger than the pinkish sideritic gangue common in the sphaleritic ores of French Gulch.

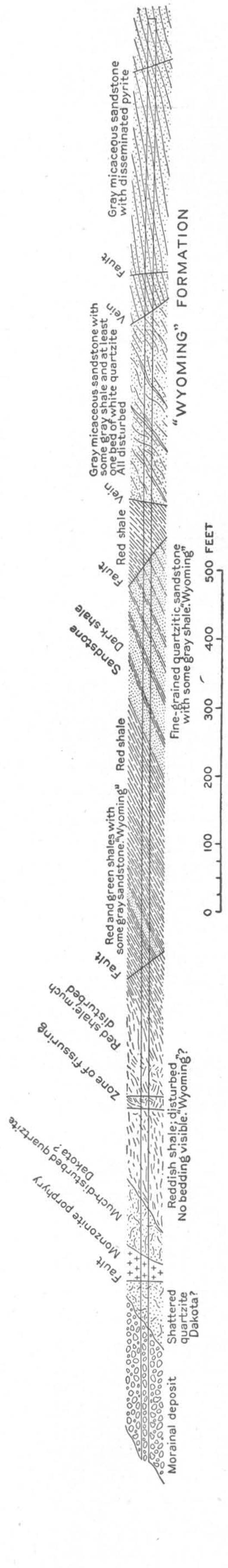


FIGURE 15.—Longitudinal section through the French Creek tunnel.

Recent reports from Breckenridge indicate that in the spring of 1910 the American Zinc Extraction Co., owner of the Little Sallie Barber, was shipping about 30 tons of zinc ore a day.

FRENCH CREEK TUNNEL.

The French Creek tunnel is on the south side of French Gulch, due south of Mineral Hill. It runs for 2,100 feet S. 12° E. under the porphyry sheet of Bald Mountain and is of interest chiefly from the section that it affords of the sedimentary beds under that porphyry. A longitudinal section through the tunnel is shown in figure 15, and the stratigraphy is described on page 71. No productive ore body has been opened in the tunnel.

PUZZLE, OURAY, AND GOLD DUST MINES.

The Puzzle, Ouray, and Gold Dust workings, situated about 1¼ miles southeast of Breckenridge, between Little Mountain and the head of Dry Gulch, are all so closely related as to be most conveniently described together.

The first shipment from the Gold Dust was made late in 1885, but the Puzzle and Ouray mines were a few years later in becoming productive. In 1890 the Puzzle and Ouray both shipped steadily from the same vein and unfortunately became involved in a legal quarrel that hampered their development for over seven years. About the year 1897 the ore began to show signs of exhaustion and although the Puzzle and Gold Dust were worked by lessees for a few years more all three of the mines had been long abandoned to ruin by the opening of 1909. During the summer of that year the Puzzle and Gold Dust workings were in part reopened under an option, with a view to thorough testing of the vein below the shallow depth to which work had been confined. The total production of the three mines could not be definitely ascertained. Local estimates, apparently reliable, make the gross yield of the Puzzle and Ouray about $960,000 and of the Gold Dust about $200,000.

The connected underground workings of the three mines are fairly extensive but not deep. The principal level of the Puzzle and Gold Dust, known as the Willard level, is shown in figure 16, which is for the most part a rough survey effected by pacing distances and determining directions with a compass. This level has its portal only a few feet above the little marshy flat just east of Little Mountain and runs nearly southeast for 715 feet as a crosscut to the Puzzle vein. Southwest of the point where the crosscut reaches the vein are the principal workings of the Ouray mine, now abandoned and inaccessible. The Ouray shaft, situated on the hillside southeast of the portal of the Willard tunnel, is said to be 368 feet deep and to extend 268 feet below the Willard level. From this level extensive stopes were opened on the Puzzle or Ouray vein southwest of the point where it crosses the side line of the Puzzle claim. No map of these workings could be found in 1909.

From the Puzzle side line the Willard level turns northeast and follows the vein for 900 feet to the Puzzle Extension shaft, 187 feet deep, situated in Illinois Gulch just above the mouth of Dry Gulch. Along nearly all of this distance the vein has been stoped to the surface. At the Puzzle Extension shaft the level leaves the vein, which here appears to split into unimportant branches, and crosscuts north

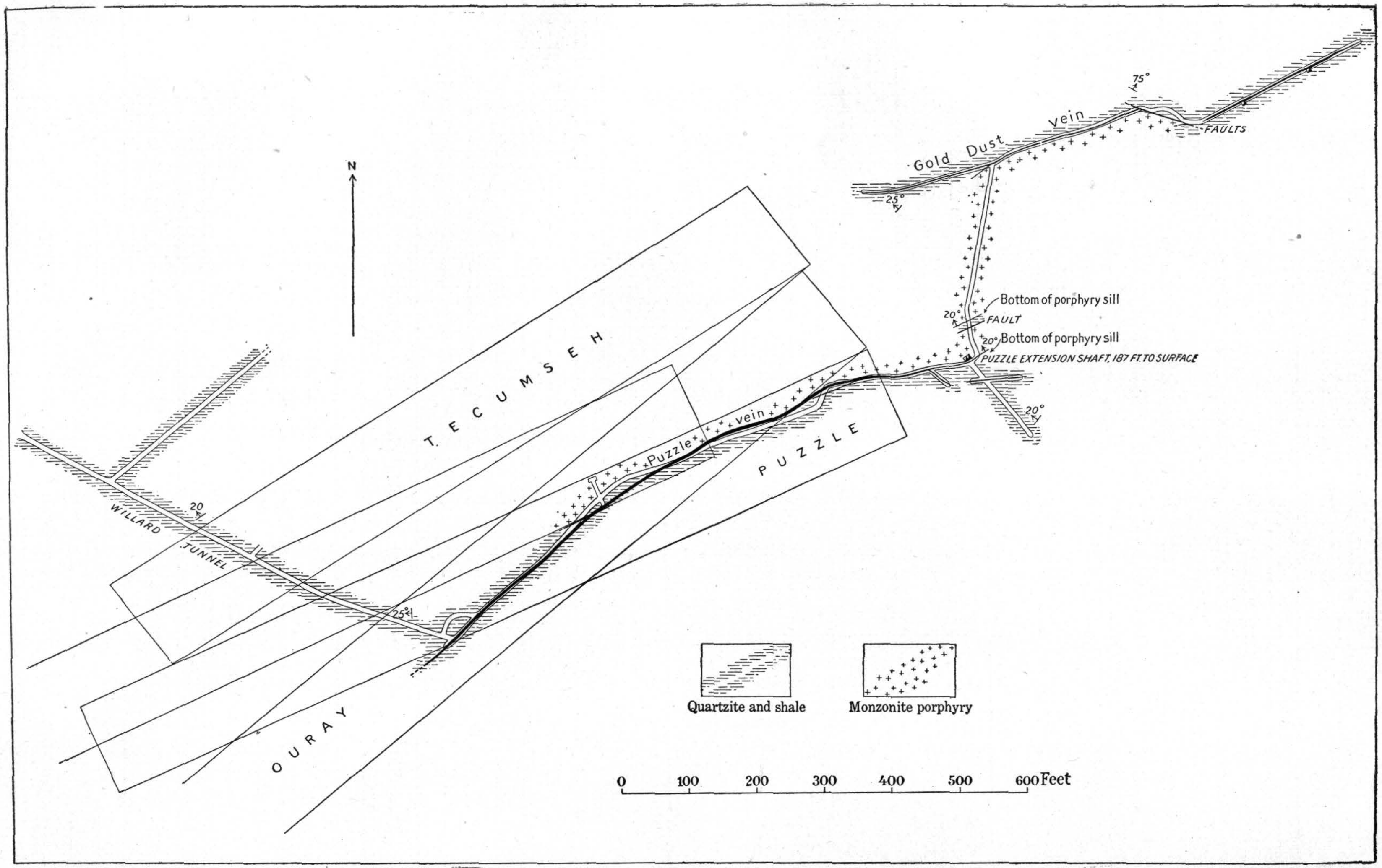


FIGURE 16.—Geologic plan of the principal level of the Puzzle-Ouray-Gold Dust workings.

for 300 feet to the nearly parallel Gold Dust vein, whose course on the surface coincides with the bottom of Dry Gulch. This vein is explored on the Willard level for approximately 800 feet and for much of this distance has been stoped. There are several old levels above the Willard tunnel on both veins, but these were not open in 1909.

The rock exposed along the outcrops of the Puzzle and Gold Dust veins is typical Dakota quartzite, just north of which, in Dry Gulch, is a strip of dark Upper Cretaceous shale, which supposedly is faulted down against the quartzite, although the fault fissure is not visible. On the Willard level the hard white quartzite is found to be associated in an inseparable way with beds of gray shale, in part calcareous. These two rocks in some parts of the mine alternate in thin beds, as may be well seen in the crosscut southeast of the Puzzle Extension shaft. The general dip of the beds is northwest at 20° to 25°, although locally they show much irregular disturbance. Both shale and quartzite are considered to belong to the Dakota formation. Between the Puzzle and Gold Dust veins, as is shown in figure 16, is a body of diorite porphyry. This is an intrusive sheet or sill, the bottom of which is exposed at the beginning of the Gold Dust crosscut, near the Puzzle Extension shaft. About 50 feet north of the shaft a fault of small throw brings the shale beneath the sill up to the level of the crosscut, but a gentle northwest dip of 20° soon carries it out of sight and the rest of the crosscut is all in porphyry, which also forms the southeast wall of the Gold Dust vein for about 300 feet.

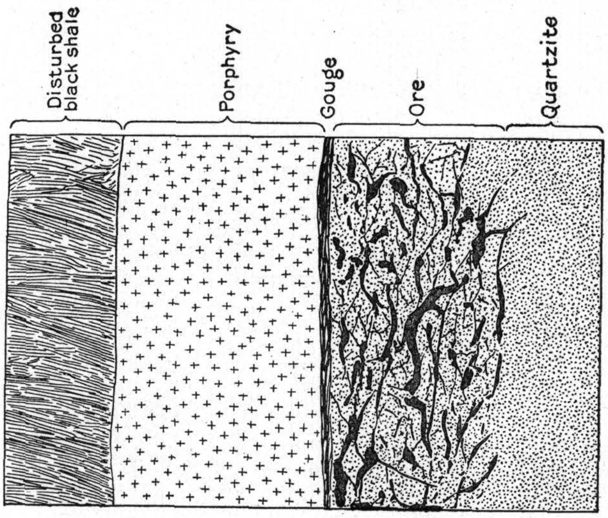


FIGURE 17.—Sketch section across a small ore body in the Gold Dust vein as stoped in 1909.

There is little opportunity for studying the veins themselves in the present workings, for most of the drifts are through or under old stopes and afford no typical exposures of ore and very few of the wall rocks. Both veins on the whole are practically vertical and appear to occupy fault fissures of small displacement. There was no opportunity at the time of visit to measure the throw along either fissure, but it is rather doubtful if it anywhere exceeds 100 feet and probably it is considerably less than that. As may be seen from figure 16, the Puzzle vein for at least 600 feet of its length lies at or close to the contact between porphyry on the northwest and quartzite and shale on the southeast. Porphyry and sediments along this stretch of the vein were evidently faulted together at the time the fissure now occupied by the vein was formed. Yet the line of this fault, and of the vein also, differs so little from the line that would be defined by the intersection of the bottom of the porphyry sill with the horizontal plane of the level as to show that no extensive displacement has occurred. The absence of any strong continuation of the Puzzle vein east of the Puzzle Extension shaft also points to the same conclusion.

At no place could any ore be seen in the Puzzle vein in 1909. According to Mr. John Nelson, who at one time was foreman in the Puzzle mine, all of the rich shipping ore was stoped from levels above the Willard tunnel. The stopes immediately above that tunnel supplied an unoxidized milling ore averaging about $12 a ton. Most of the shipping ore was sent to Denver, but the composition of one lot that went through the local sampling works is given in the table on page 108. The shipping ore from the Gold Dust vein was similar, as may be seen from the same table.

In 1909 a small stope was being worked on the Gold Dust vein, about 75 feet above the first raise shown east of the fault in figure 16. The best ore, consisting of shattered, recemented shale and quartzite carrying pyrite, sphalerite, and a little galena, shows considerable disturbance that has to some extent obscured the original relation of the ore to the country rocks. At this place a little soft altered porphyry carrying bunches of sphalerite, probably a dike, lies on the south side of the ore. The general relations of the ore to the rocks in this stope are indicated in figure 17.

WASHINGTON MINE.

The Washington mine is situated 1½ miles southeast of Breckenridge, on the slope between Illinois and Dry gulches. This is one of the older mines of the district, and as early as 1883 was giving employment to over 30 men. A 20-stamp mill was built about 1885. At this time and for a few years later the mine was worked through the Watson shaft, situated at an elevation of 10,550 feet on the spur connecting Nigger Hill with Bald Mountain. The mine continued steadily productive until 1891, after which it appears to have been turned over to lessees, who made shipments up to 1897 and perhaps later. The total output of the Washington mine, as given in a prospectus issued by the Washington-Joliet Mining & Milling Co., capitalized at $1,500,000, is between $400,000 and $500,000. There is no reason to suppose that this statement is exaggerated.

The underground workings consist of the old shaft on the hill, from which considerable drifting and stoping was done, and of six tunnels on the slope from the shaft down to Illinois Gulch. Of these the most important is the Cornish Tunnel, which follows the Washington vein in a general northeast direction for about 1,400 feet and connects with the shaft at a depth of 250 feet. At 115 feet below the Cornish tunnel is the Berlin tunnel, supposed to be on the Emmet, a vein parallel with and a short distance southeast of the Washington. From 600 to 700 feet southeast of these tunnels are the Christensen, Mayo, and Weinland tunnels on the Mayo vein, which has produced ore to the value of at least $50,000. The Washington and Emmet veins are reported to dip northwest at 65° to 70°, but the Mayo, approximately parallel with them in strike, dips southeast. From 250 to 300 feet southeast of the Mayo vein is another vein striking N. 25° E. and dipping northwest at 75°. This is developed in the Horn tunnel.

All the Washington workings, of which, so far as known, no complete map exists, were inaccessible in 1909 and nothing could be learned at first hand of the character of the veins or of the relations of the rocks that they traversed. This is especially regrettable, as the long Cornish tunnel, which begins in quartzite and connects with the shaft sunk in monzonite porphyry and which probably crosses a fault between these two rocks (see Pl. I, in pocket), ought to furnish an interesting underground section that would throw considerable light on the structure of the district.

The ore of the Washington appears to have been not unlike some of the Puzzle and Gold Dust ore, carrying silver and lead with some gold. The composition of one lot shipped from the Horn tunnel, and therefore not from the main Washington vein, is given on page 108. This evidently was partly oxidized ore.

JUMBO MINE.

The Jumbo and Buffalo claims were first developed in the summer of 1884 by E. C. Moody, who, in August of that year, had a shaft 50 feet deep exposing a vein of rich gold ore in porphyry. In the following year he sold his claims for $25,000 and the Jumbo mine entered upon a short period of steady production, the output toward the end of 1885 amounting to 35 tons a day, which was treated at the Eureka mill, near the mouth of Cucumber Gulch. In 1888 the mine was closed, but it was reopened in 1890 and is known to have been producing in 1893 and again in 1897. In 1898 it was worked by lessees and shortly after appears to have been abandoned to decay. Its total production can not be learned but probably exceeded $300,000. The ore is reported to have averaged from $8 to $9 a ton down to the bottom of the oxidized zone, where work stopped. Some of the concentrates (although for what year is not known) contained 0.46 ounce of gold and 1.9 ounces of silver to the ton, which would indicate an ore of considerably lower grade than that reported above.

The Jumbo vein is mainly in the narrow strip of diorite porphyry that, as shown on Plate I (in pocket), separates the quartzite of Gibson Hill from the shale forming the gentle slope southwest of Gold Run. The vein strikes nearly N. 60° E. and lies very close to the quartzite; in fact, a small spur vein of exceptionally rich ore is said to have extended into the quartzite. Material on the dump indicates that the deposit is a stringer lode, the fissures being filled with pyrite almost free from gangue. Oxidation of the pyrite produced a free-milling ore containing some coarse gold. Apparently the pyritic ore below the zone of partial oxidation proved to be of too low grade for profitable working.

EXTENSION MINE.

The Extension workings, formerly owned by the Double Extension Gold Mining Co., lie just east of the Jumbo workings, and, like them, are too dilapidated to permit examination. The deposit was discovered about the same time as the Jumbo but was worked to a later date, the company treating the ore in a 20-stamp mill at the mine. The Extension was one of the prominent mines in the district in 1892 and 1893 and was supplying $25 ore from a stope up to 20 feet wide. The present owner bought the property at a delinquent-tax sale and could furnish no information regarding the underground workings. The ore apparently occurs in quartzite and so far as is known was not worked below the limit of oxidation.

LITTLE CORPORAL MINE.

The Little Corporal mine is in quartzite just west of the Jumbo workings. The vein, which afforded a gold-silver ore, was worked from a shaft which has long been abandoned. Nothing could be learned concerning the character of the deposit.

CHAPTER X.

STOCKWORKS AND VEINS OF THE GOLD-SILVER-LEAD SERIES.

DISTRIBUTION.

The ore deposits of the gold-silver-lead series are all in the northeastern half of the district and are as characteristically associated with the quartz monzonite porphyry as are the veins described in the last chapter with the monzonite porphyry. The mines in ore bodies belonging to this group are the Wire Patch, on the south slope of Farncomb Hill; the Cashier, in Browns Gulch, and the near-by I. X. L., on the Swan; the Hamilton, in Summit Gulch; and the Jessie, on the northeast side of Gold Run. None of these mines is now in a condition to permit thorough examination, and the Hamilton was the only one where any work whatever was in progress in the summer of 1909.

GENERAL STRUCTURAL FEATURES.

A distinctive feature common to these deposits is the occurrence of the ore in much-fissured and minutely veined rock, ordinarily quartz monzonite porphyry, rather than in well-defined lodes. The fissuring may vary widely in character. In the Hamilton ore bodies it is concentrated along nearly parallel zones, so that the pay shoots have a certain regularity and might be classed as stringer lodes having widths up to about 15 feet and being separated from each other by 50 feet or less of relatively barren porphyry. The ore as a whole, however, has no definite walls. The adjacent porphyry is also more or less fissured and contains many small stringers of sulphides.

In the Jessie mine there is not the same general agreement in direction of the fissures. Certain groups of them are approximately parallel, but these are associated with others having decidedly different strikes. In many places one set joins or crosses another without any general displacement of either. As in the Hamilton mine, however, there is a decided tendency of the fissures toward a lodelike grouping, as may be seen from figure 18 (p. 145). At the Jessie mine a mass of porphyry, oval in plan, fully 900 feet long, 600 feet wide, and 300 feet deep, has been fissured in many directions, but especially by fractures striking from east to northeast. The whole is thus a low-grade stockwork; but mining has in the past been confined to those zones in which the fissures are closely spaced and most of the stopes are such as might have been opened on ordinary veins of moderate width. As may be inferred from figure 18 there is generally no great persistency to these lodelike zones of stringers. Some die out within surprisingly short distances or merge with other zones.

In the Cashier mine the principal ore body appears to have been a rotund mass of veined porphyry, which was stoped as a whole. Details of the fissuring are not now discernible in this mine.

The ore body of the I. X. L. mine as visible in the lower tunnel is a shattered mass of quartzite intricately intruded by quartz monzonite porphyry, the fissures and interstices in the mass being partly filled with sulphides. Inasmuch as the country rock is largely quartzite this deposit is regarded as less typical of the group than the others here described. The Wire Patch ore bodies are in some respects intermediate between those of the I. X. L. and Cashier mines, as they occur in irregularly fissured quartz monzonite porphyry and also in porphyry crowded with fragments of sedimentary rock—in this case shale.

THE ORES.

The deposits of this group yield generally a low-grade pyritic ore, concentrated principally for its gold and silver contents. There may be or may not be enough lead present to add to the value of the product. Mineralogically they consist of pyrite, sphalerite, and galena in a gangue of sericitized porphyry. Report indicates that the oxidized and partly oxidized upper portions of these deposits were considerably richer in the precious metals and in lead than the deeper sulphides, and it is known that bunches of rich ore containing galena and native gold were found in some of the upper workings. The greater part of the sulphides fills small open fissures (see Pl. XXVI, *B*, p. 126), but the veining is associated with some replacement. In the Jessie mine this metasomatism does not result in any general replacement of the porphyry by sulphides, so far as observed, but pyrite, sphalerite, and galena all develop sporadically at the expense of the orthoclase phenocrysts. In the Wire Patch ore bodies, however, the sulphides appear to have replaced the porphyry bodily to some extent.

EXAMPLES AND DETAILED DESCRIPTIONS.

JESSIE MINE.

INTRODUCTION.

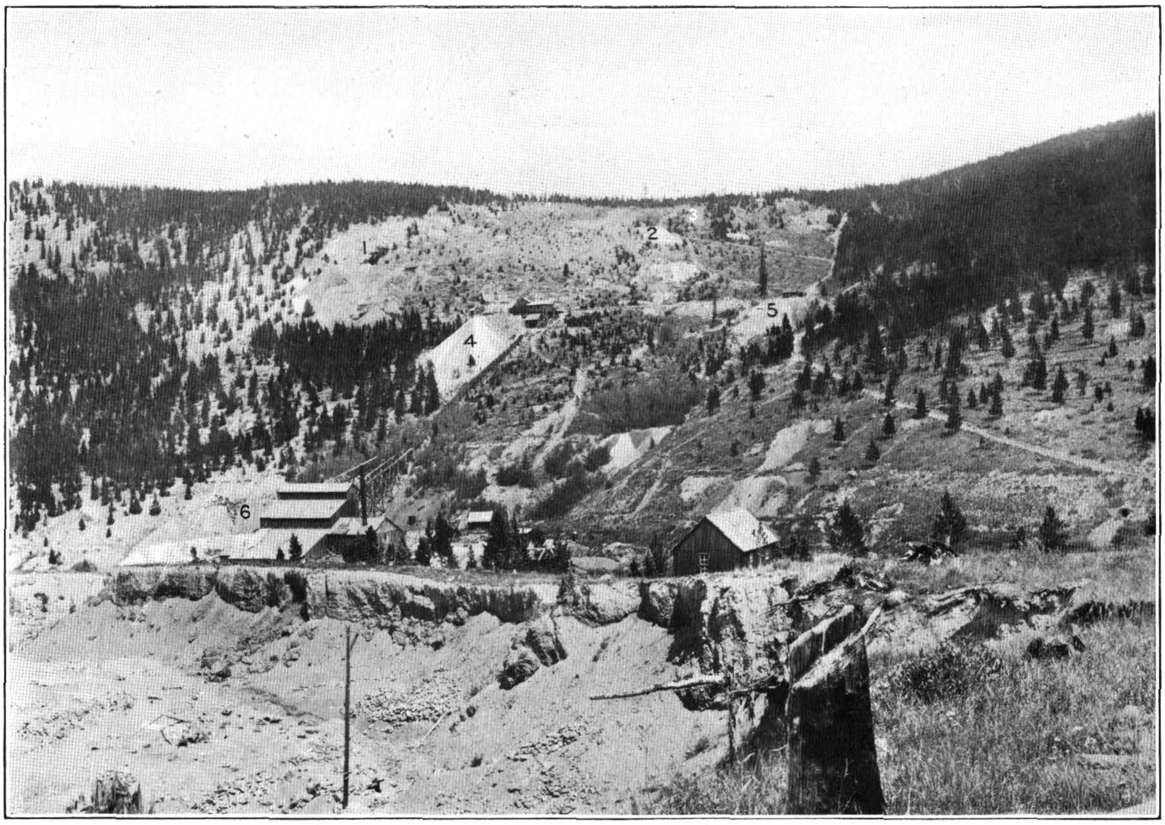
The Jessie mine (see Pl. XXIX, *A*) is situated on the northeast side of Gold Run, about 2½ miles northeast of Breckenridge. The group comprises 44 patented claims, covering a 200-acre strip of ground that extends from Gold Run to Galena Gulch. The productive part of the group, including the Jessie, May B., Baden Baden, and Berlin claims, lies on the slope overlooking Gold Run. Work on these claims appears to have begun in 1885 by E. C. Moody,[1] a prospector who had previously been successful on Farncomb and Gibson hills. In 1886 he and his partner, Irwin, had a 10-stamp mill on the site of the present Jessie mill. A few years later the claims now composing the Jessie group appear to have passed into the hands of the Gold Run Mining Co., which early in 1892 was succeeded by the Jessie Gold Mining & Milling Co., capitalized at $400,000. A few shipments were made during that year, a new mill was finished in 1894, and the mine appears to have been steadily productive during 1895–96. In 1897 the company suspended operations, and in the following year the property was leased to the Dania Gold Mining Co. In 1899 the mine was leased to B. S. Revett, who remodeled the 40-stamp mill, added concentrating tables to the plates previously in use, and worked the mine for a time by stoping only the richer sulphide streaks, together with such oxidized ore as was available. In 1906 the Jessie mine was leased to James T. Hogan, who assigned the lease to the Jessie Consolidated Mines Co., capitalized at $1,500,000. This company, however, does not appear to have resumed mining and no work whatever was in progress in 1909. The total production of the Jessie has been variously estimated at $800,000 to $1,500,000.

The principal reasons why the mine has not been more steadily and successfully worked appear to be the excessive dead work required to find the higher-grade streaks, the irregularity and frequent lack of persistency of these when found, and failure to obtain a high percentage of extraction in the mill. From all that can be learned the extraction prior to 1899 (when concentrating tables were added) was only about 40 per cent. Even after concentration was introduced the recovery was certainly not over 80 per cent and probably was under 60 per cent.

UNDERGROUND WORKINGS.

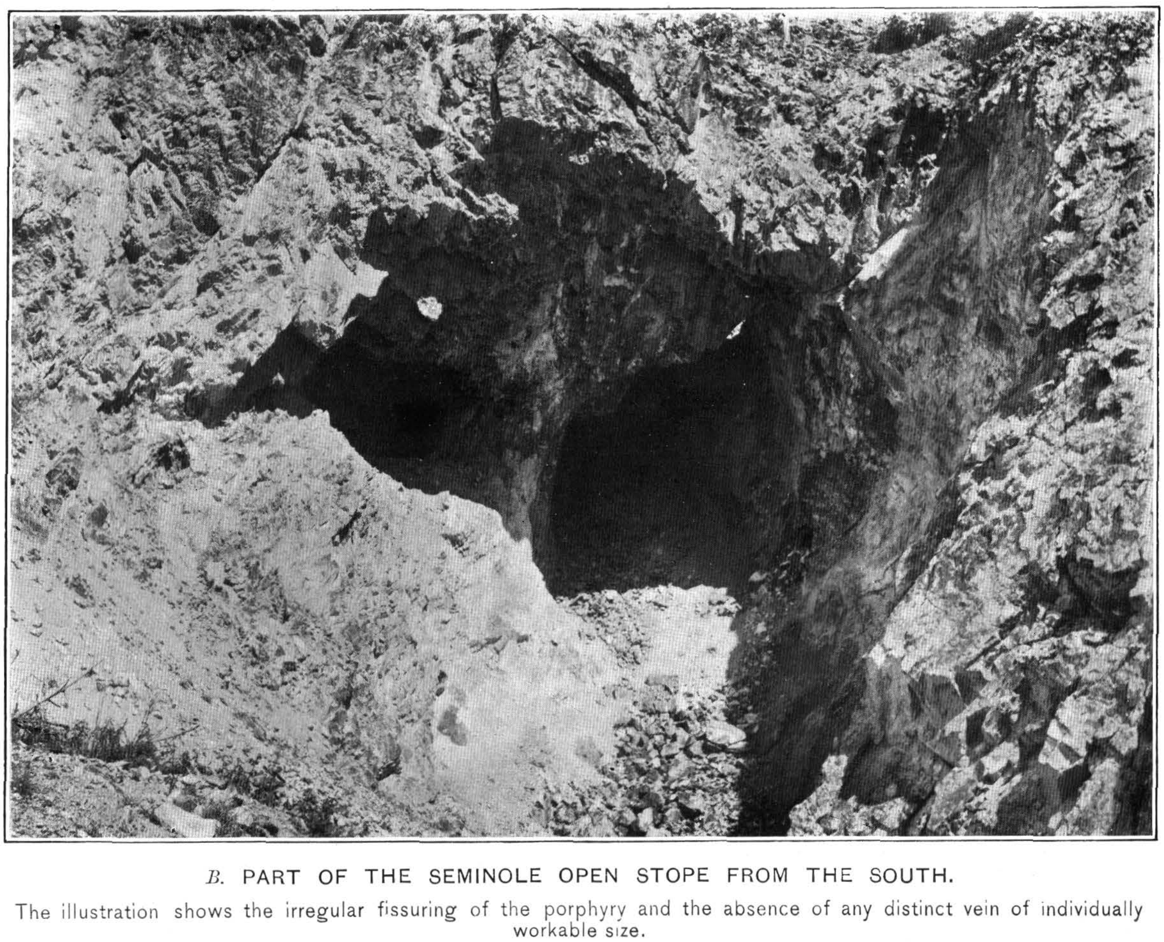
The underground workings of the Jessie are shown in plan in figure 18. Only one level, that of the Glenwood and Jessie tunnels, is now accessible. Above this are some old upper levels and stopes, some of which open into pits or "glory holes." About 180 feet below the Glenwood level is the Hattie tunnel, sometimes called the Shale tunnel from the fact that it

[1] Moody's first work was on the Bonanza and Seminole claims, which do not appear under those names on Plate II (in pocket). Whether they were never patented or were recorded under new names, as was done in some other cases, I do not know.—F. L. R.



A. THE JESSIE MINE FROM THE SOUTH.

1. Seminole open stope. 2. May B. open stope. 3. Disbrow open stope. 4. Glenwood tunnel. 5. Jessie tunnel. 6. Hattie tunnel. 7. Quincy tunnel. In the foreground is part of the Gold Run placer.



B. PART OF THE SEMINOLE OPEN STOPE FROM THE SOUTH.

The illustration shows the irregular fissuring of the porphyry and the absence of any distinct vein of individually workable size.

is chiefly in that rock. This tunnel and the Quincy tunnel, 30 feet lower, were both caved near their portals in 1909 and could not be reached through the raises connecting them with the Glenwood level. The total vertical range of the workings from the Quincy tunnel to the crest of the ridge is about 350 feet.

GEOLOGIC RELATIONS.

All except a wholly inconsiderable part of the ore from the Jessie mine has come from quartz monzonite porphyry. As may be seen from Plate I (in pocket) this porphyry is part of a large and exceedingly irregular mass that extends from Delaware Flats southeastward nearly to Farncomb Hill and is intrusive into the Upper Cretaceous shale. Some parts of the mass cut across the shale as dikes, other parts are sills, and still other parts are too irregular to be classed under either form of intrusive body.

As shown by figure 18, the accessible workings of the Jessie are nearly all in the porphyry, shale being exposed at only three localities. One of these is in the western part of the mine at the end of the Seminole Crosscut No. 1. At this place the porphyry overlies the shale, the

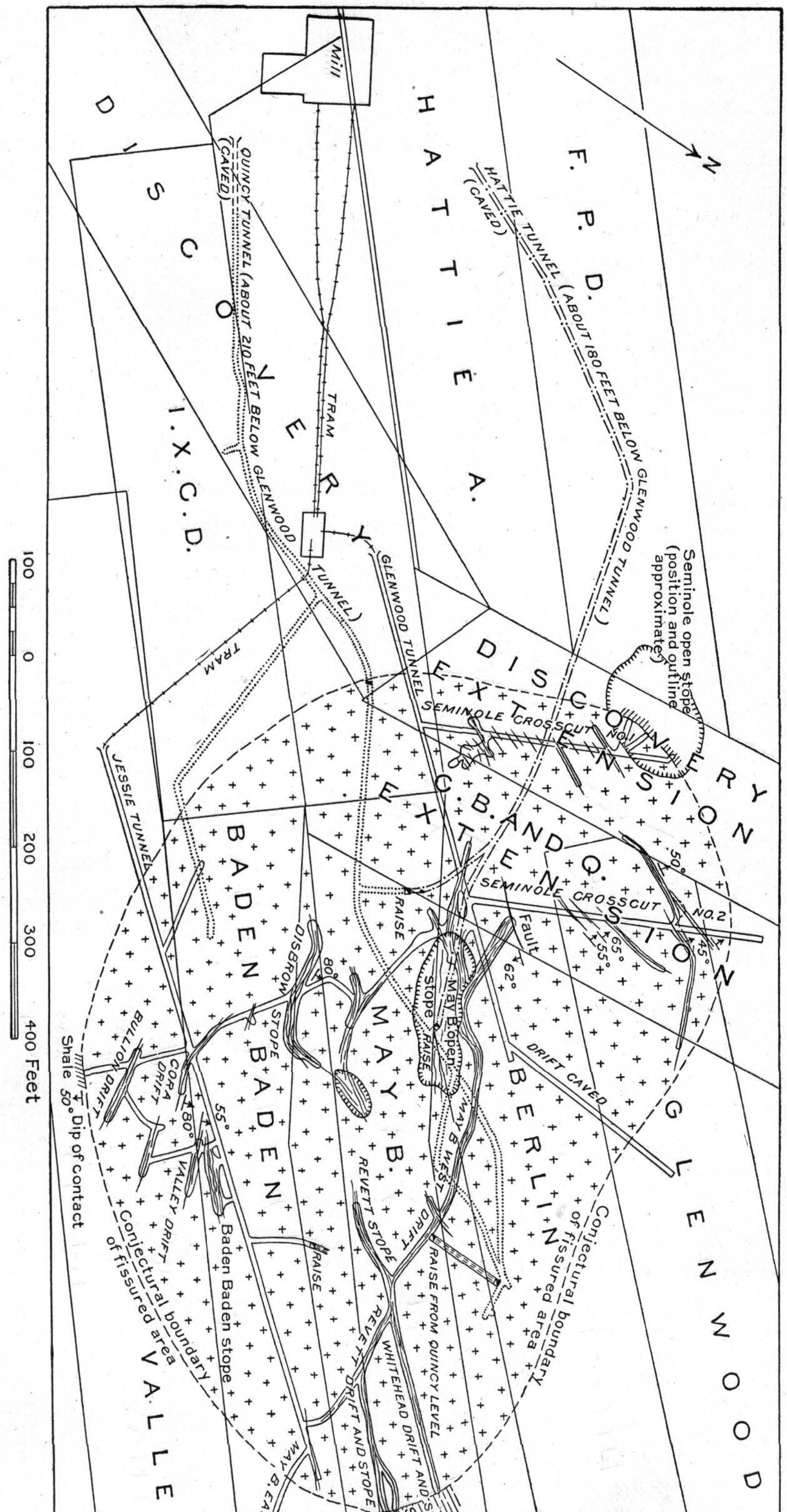


FIGURE 18.—Plan of the principal levels of the Jessie mine. Old upper workings omitted. Geologic data and representation of fissuring apply only to the Glenwood-Jessie level.

contact dipping 20° E. It appears to be a contact by intrusion, although there has been some later movement along it. In the northern part of the mine the Revett and Whitehead drifts both reach the shale, with which the porphyry here is in close igneous contact, cutting vertically across the sedimentary beds. Another contact is exposed southeast of the Jessie tunnel. Here the contact surface dips to the east and is accompanied by some gouge, due to movement since the porphyry was intruded. These exposures are too few to afford much information as to the shape of the porphyry mass at the Jessie mine. Undoubtedly much more could be learned were the Hattie and Quincy tunnels open. These evidently go through much shale, and although in the eastern part of the mine the porphyry may continue indefinitely downward, in the western part it lies upon shale, perhaps connected with small dikes in that rock.

ORE BODIES.

The ore of the Jessie mine consists mineralogically of pyrite, sphalerite, and galena associated with altered porphyry as gangue. The galena as a rule occurs only in the fissures or in the immediate vicinity of fractures. Its presence is invariably a sign of good ore. Sphalerite, although present chiefly in veinlets, has a little wider range than the galena as a metasomatic constituent of the altered porphyry. Pyrite occurs both in the fissures and widely disseminated throughout the altered porphyry. It is generally of low grade, the ore formerly mined ranging in tenor from $3 to $6 a ton. The ore from the Revett stope, which is reported to have yielded in all about $77,000, is stated, in a report made by Mr. Jeremiah Mahoney, to have averaged $4.03 in gold and 48 cents in silver to the ton. Some idea of the character of the concentrates produced in 1897 may be had from the sampler analysis given on page 108.

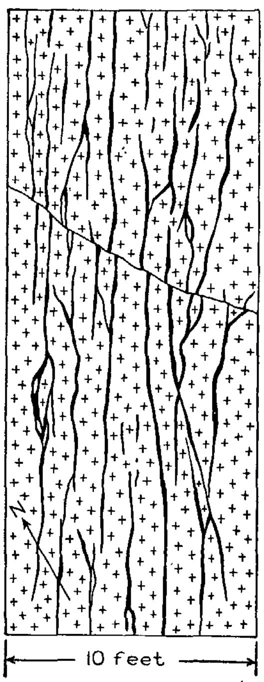


FIGURE 19.—Sketch of stringer lode in the May B. stope of the Jessie mine.

There is no vein in the ordinary sense. The entire deposit is essentially a stockwork in porphyry, oval in plan, with the small end of the oval directed to the northeast. The length of the metallized area is about 900 feet and its greatest width about 700 feet. Nearly all of the porphyry within these bounds is traversed by small veinlets (see Pl. XXVI, *B*, p. 126) carrying pyrite, sphalerite, and less galena or contains these minerals disseminated through it, particularly as metasomatic replacements, accompanied by sericite, in the large orthoclase phenocrysts of the porphyry. Along certain zones, however, the fissures are more closely spaced and more regular in trend than elsewhere, the proportion of sulphides to waste is greater than the average for the stockwork as a whole, and it is to these zones, many of them having more or less of a lodelike character, that stoping has been confined. The general appearance of such a zone, showing the branching and crossing of the sulphide veinlets, is represented in figure 19, which is a sketch of the back of part of the May B. stope. As a rule there are no definite walls to the stopes, and groups of stringers that may be nearly parallel and present the appearance of a strong stringer lode for 100 feet or more along the strike finally die out or merge with another group of different trend. The more pronounced zones of fissuring strike from northeast to east. The dip in general is to the northwest and ranges from 30° to vertical. A few zones dip to the southeast. Most of the veinlets of sulphides are less than an inch in width and fill cracks of no great individual persistency. Even some of the larger stringers, up to 4 inches in width, can be traced until they die out completely and the short distance within which some zones, stoped to widths up to 15 feet, dwindle to a few insignificant close cracks when followed along the strike is a marked characteristic of the deposit. Neither before nor after the deposition of the ore has there been any considerable movement along the fissures by the slipping of one wall past the other. Consequently seams of gouge are exceptional and where present occupy fissures that do not belong to the ore-bearing group. Evidently the ore-bearing fissures were formed by stresses that were relieved merely by the opening of many small cracks in the porphyry and that were not productive of much displacement.

No important body of ore has yet been found in the shale. The fissures either end at the contact or continue in diminished number and smaller size for a few feet into the shale and then gradually die out. The Whitehead stope at its northeast end was carried for a few feet into the shale, but the quantity of ore found in that rock was evidently small.

The depth to which the stockwork extends is not determinable from the workings now open to examination, but there is good reason to conclude that a large part of the metallized porphyry is underlain by shale on the Hattie and Quincy levels in some such way as is indicated in figure 20. Whether any considerable body of porphyry extends much below these levels can not be determined without reopening them and prospecting by drilling or sinking winzes. Whether the entire mass of porphyry within the oval curve defining the general limit of metallization could be profitably worked by open-pit or quarrying methods is a question that could be answered only after careful and thorough sampling. Obviously the original average tenor of the whole has been much reduced by the selective mining of the past.

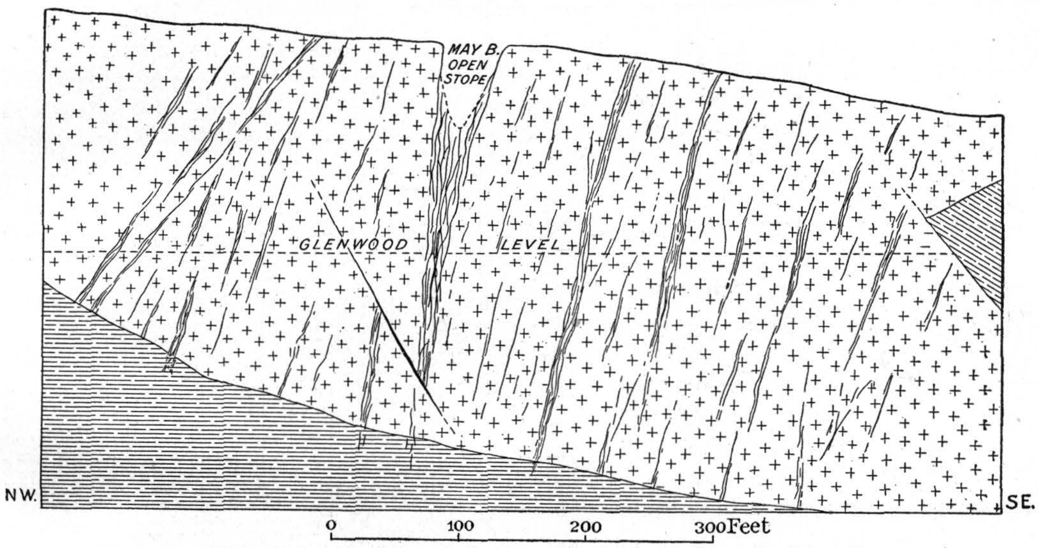


FIGURE 20.—Diagrammatic section through the porphyry of the Jessie mine, showing the general character of the fissuring.

HAMILTON MINE.

The Hamilton mine is at the head of Summit Gulch, a mile south of the Swan and about 2 miles a little west of north from Lincoln. The mine attracted little notice until about 1893, but from that time until the summer of 1899 it appears to have made steady shipments of concentrates from a little 10-stamp mill at the mine. After lying idle for 10 years the Hamilton mine has recently been reopened by the White Cloud Mining Co. The total gross production is given by the present owners as about $400,000.

So far as could be learned there is no complete map of the underground workings in existence. The development is by three main tunnels and one sublevel, all on the east side of the gulch. The upper or No. 1 tunnel, from which most of the ore was taken in early days, is about 200 feet above the bottom of the gulch, where are situated the mill and the portal of the lowest tunnel, known as the Tip Top tunnel or fifth level. About halfway between these two levels is the Blacksmith tunnel, or third level. The present operators are making no effort to reclaim the old upper workings, but are confining their attention to exploratory work from the Tip Top tunnel and from another tunnel, known as the Homestake, that lies south of the Tip Top and 60 feet higher.

The No. 1 tunnel crosscuts in a northeast direction a series of nearly east-west veins, which in order from south to north are the Sheridan, Surprise, Gulch, and Righthand veins. The strikes of these vein range from N. 85° E. to N. 63° E. They dip north at angles ranging from 75° to vertical. These veins are stringer lodes in quartz monzonite porphyry, which is part of the same intrusive body that contains the Jessie and Cashier ore bodies. The lodes have no definite walls, are generally less than 50 feet apart, and are merely zones along which the fissuring has been greater than in the intervening slabs of porphyry. In some places two of the so-called veins, elsewhere fairly distinct, come together and form a single large ore body. The old stopes on the veins, as nearly as could be estimated without maps or measurements, are up to 150 feet long, from 5 to 15 feet wide, and extend from points near the surface down to the third level, or through a vertical range of 150 to 200 feet. In general the stopes on one fissure zone are nearly opposite those on another.

One noteworthy geologic feature of the mine is the occurrence of large blocks of black Upper Cretaceous shale in the porphyry. These are bounded in part by igneous contacts and in part by faults that have brought the shale into juxtaposition with the porphyry. No ore of any importance is known in the shale and those who have worked in the mine stated that the veins end at the shale. At one place accessible in 1909 the Sheridan vein was observed to end at the surface of a body of shale, but the contact at this place appeared to be due to faulting of later age than the deposition of the ore.

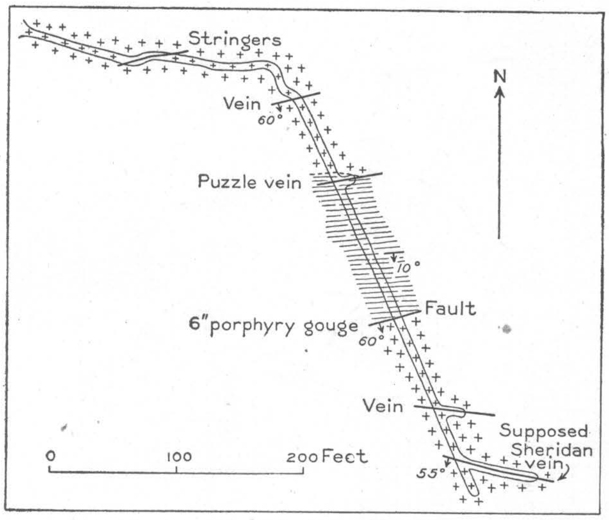


FIGURE 21.—Geologic sketch plan of the Tip Top tunnel of the Hamilton mine.

The ore is similar in general character to that of the Jessie and Cashier mines, consisting of stringers of pyrite, sphalerite, and galena in pyritized and sericitized porphyry. There is more pyrite and less sphalerite than in the Jessie, and the best ore from the old stopes below the No. 1 tunnel shows incipient oxidation. Although most of the sulphides fill fissures, they have to some extent replaced the porphyry. Some crude ore, shipped in 1903, probably partly oxidized, had approximately the composition given in the table on page 108.

The concentrates, which have been the chief product from the mine, owed their value mainly to their contents in silver and gold, the lead and zinc having been almost negligible.

The newer exploratory work on the Tip Top level is shown in plan in figure 21, made from a rough compass survey. It will be seen that the tunnel passes for about 125 feet through a body of shale, which is bounded on the north by a close igneous contact and on the south by a fault associated with about 6 inches of soft gouge. In the shale near its north contact with the porphyry is a little tight stringer of pyrite which was stated to have afforded 2 ounces of gold and 8 ounces of silver on assay. The porphyry south of the shale is traversed by small stringers of pyrite with a little galena, quartz, and calcite. The largest of these stringers is supposed by those in charge of the development to be what is known above as the Sheridan vein. This, however, is open to question.

CASHIER MINE.

The Cashier mine is on the east side of Browns Gulch, two-thirds of a mile south of the deserted settlement of Swan City and 1 mile east of the Hamilton mine. The workings are chiefly on the Cashier and Smuggler claims. Mining on these claims began in the early eighties, but the mine attained no prominence until about 1898, when a 40-stamp mill was begun. This was finished late in the following year, and although only 20 stamps were actually used, the mine was actively worked for about 5 years. It was then abandoned, and in 1908 the mill was torn down and the machinery removed. The total output has not been ascertained but was probably between $200,000 and $500,000.

The mine is developed by two tunnels and an intermediate level, the general plan of the underground workings as they were in 1902 being shown in figure 22. In 1909 there was no one whatever at the mine, and the lower tunnel, about 100 feet above the bottom of the gulch, could not be entered. A little stoping apparently was done from this level, but most of the ore extracted came from above the intermediate level, which is about 60 feet above the first or lowest level. The third level is about 75 feet above the intermediate level and in the eastern part of the great stope is from 80 to 100 feet below the surface of the hill.

All the Cashier workings that were accessible in 1909 are in quartz monzonite porphyry forming part of the same irregular intrusive mass that contains the ore of the Jessie mine.

The ore body, like that of the Jessie, is a stockwork, the ore consisting of fractured porphyry traversed by stringers of pyrite, sphalerite, and a little galena. The dominant fissuring strikes northeast, but owing to the height and size of the stopes and the absence of fresh working faces little can be ascertained regarding the details of the fissuring and veining. It is certain that the fracturing is irregular and that the ore bodies have no definite walls. The principal pay shoot was cut in the upper tunnel about 150 feet from the portal and was stoped for a distance of over 200 feet from southwest to northeast, to widths of more than 60 feet. The stope is untimbered and forms a vast irregular chamber extending from the second level nearly to the surface. This impressive cavity is only partly represented in figure 22, having been considerably enlarged, especially on the second level, since the surveys were made on which that map is based.

The ore of the Cashier mine is of low average grade and has a smaller ratio of silver to gold than in the Jessie mine. Pyrite is the principal sulphide and both sphalerite and galena are apparently less abundant than in the Jessie ore. Occasionally small rich bunches were found and some specimens from the upper workings of the Cashier, preserved in Breckenridge, contain wire gold embedded in galena and sphalerite.

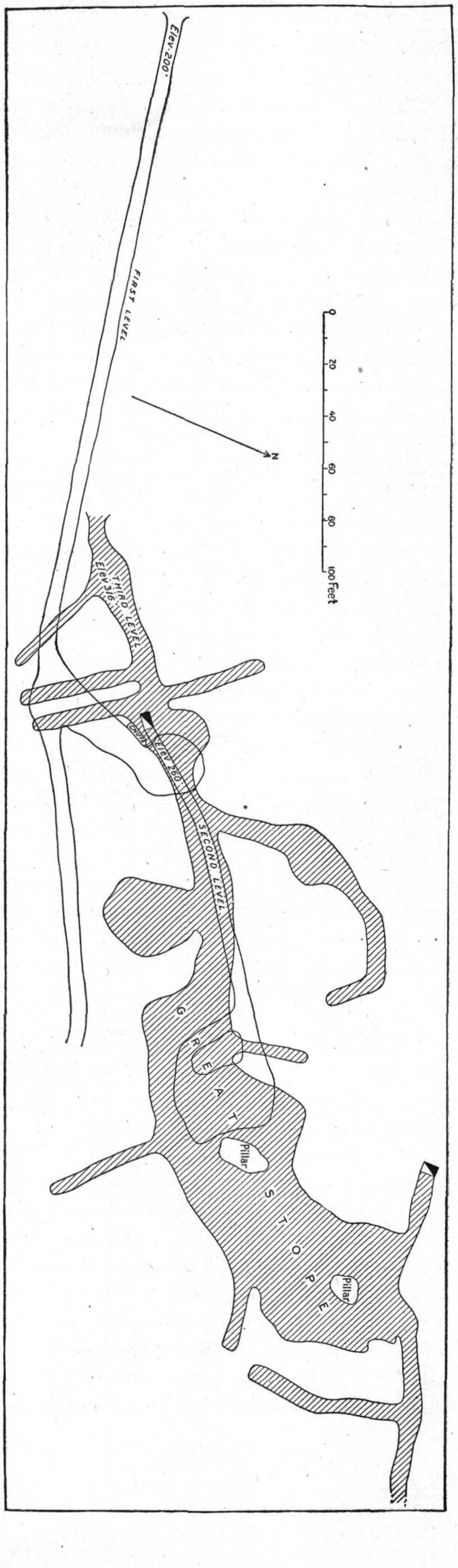


FIGURE 22.—General plan of the Cashier mine.

The approximate composition of a shipment of oxidized ore from the Cashier mine made in 1904 is given on page 108.

I. X. L. MINE.

The I. X. L. mine is on the south side of Swan River, a little less than half a mile east of the mouth of Browns Gulch and directly northeast of the Cashier, the ends of the Cashier and I. X. L. claims being only about 300 feet apart.

Work on the I. X. L. claim began in 1881, and the mine was equipped with a mill in 1883. Shipments of concentrates continued up to the year 1898, since when the mine has lain idle, the upper workings have caved, and the mill has fallen in ruins. The I. X. L. appears never to have been one of the larger shippers and, like many other mines in the district, suffered from mismanagement. Its total production is not known.

The principal underground workings consist of two tunnels. The upper one, which enters the hill about 300 feet above the meadows of the Swan and connects with stopes that supplied most of the ore formerly milled, is no longer accessible. A newer tunnel, about 200 feet lower, runs S. 32° W. for 800 feet and connects through 100 feet of drift to the west with a stope on an ore body lying nearly under the ore stoped from the upper level but not known to be part of the same pay shoot.

The geologic relations of the I. X. L. ore are very unsatisfactorily revealed. The lobe of shale shown southwest of the portal of the lower I. X. L. tunnel on Plate I (in pocket) is probably underlain by porphyry in igneous contact with it, for no shale occurs in the tunnel. South of the tunnels the porphyry as exposed in the vicinity of the three shafts shown in line on Plate I evidently contains included blocks of quartzite, but the shapes and dimensions of these blocks are not shown by surface exposures. The lower tunnel is mainly in quartz monzonite porphyry that is part of the same mass within which are the ores of the Cashier, Hamilton, and Jessie mines. This porphyry is thoroughly and irregularly fissured and contains many small stringers of sulphides. The ore body on this level, however, is a mass of quartzite fully 100 feet across from east to west and from north to south. How much larger it is and what its thickness is can not be determined without further development. This mass of quartzite was intricately fissured at the time of the porphyry intrusion, and the fissures were filled with the magma. This complex mass of quartzite, traversed by countless branching and crossing dikelets of porphyry, was subsequently shattered, and the resulting fissures and irregular interstices were filled with pyrite, sphalerite, galena, and quartz, with a little chalcopyrite, and locally some bismuthinite. Further details regarding this ore have been given on page 108.

No information could be obtained as to the tenor of the ore, which evidently belongs to the low-grade milling class.

WIRE PATCH MINE.

The Wire Patch mine is situated on the southwest slope of Farncomb Hill, 4 miles east of Breckenridge. It takes its name from the Wire Patch placer claim or "patch," from which the main tunnel has been driven into the hill under the Frederick the Great, Elephant, Emperor, Queen of the Forest, and other lode claims. The Elephant ore body, from which has come most of the production of the Wire Patch mine, appears to have been discovered about the year 1882, and by the end of 1886 was credited with an output of $75,000. The total product from the Emperor claim at this time amounted to about $15,000 and that from the Queen of the Forest to $8,000. In 1888 the Wire Patch Gold Mining & Milling Co. began operations with a new Huntington mill. The mine was idle in 1889, and although operations were resumed in 1890 the company apparently was not successful, and in August the mine and mill were leased to Henry Farncomb. For the next few years there is little mention of the mine in local annals, although it is known to have been worked by lessees in 1897 and to have been reopened after a period of idleness in 1899. In 1908 the property was under lease to the Pitt Ores Co., of Pittsburg, which carried on some development and milled some ore, but the mine was again idle in 1909.

The general plan of underground development of the Wire Patch mine, including also some of the old tunnels of the Ontario mine, is shown in figure 23, compiled from several imperfect maps, no complete and accurate plat of the workings being in existence. The lowest or Mill tunnel enters the south slope of Farncomb Hill a little over 100 feet above French Creek and runs N. 35° E. for 596 feet. This tunnel was projected to reach ore bodies known in the upper workings, but has never supplied any ore.

About 126 feet above the Mill tunnel is the Elephant tunnel, which at points about 300 and 500 feet from its portal connects with irregular stopes in quartz monzonite porphyry. The Elephant tunnel pursues a devious northeasterly course through the hill and connects at its face through a raise with the Grove tunnel, about 200 feet higher, whose portal is on the north side of the hill. The Grove tunnel has caved in. The Smith-Emperor and Queen tunnels, on the southwest slope of the hill above the Elephant tunnel, have long been abandoned. They connect with the bottom of an open pit, about 100 feet long and 50 feet deep, in an ore body on the Queen of the Forest and Emperor claims. Still higher up the hill and west of the tunnels just mentioned is the long-disused Ontario tunnel, which follows a general easterly course and crosscuts six or more small veins in shale.

The rocks of the Wire Patch mine are Upper Cretaceous shale intruded by quartz monzonite porphyry. The shale has a general dip to the northeast of about 25°. It is, however, much disturbed by the intrusion of the porphyry, which cuts it irregularly, as may be seen from the relations of the two rocks shown in figure 23. A characteristic feature of the porphyry near its contact with the shale is the inclusion of very abundant fragments of the latter rock. In some places there is a gradation, through a distance of 100 feet or more, from porphyry containing a few bits of shale to a mass of shattered shale held together by a mesh of porphyry and having the general appearance of a breccia. The porphyry magma, which appears to have been erupted in a fairly fluid condition, evidently split off and caught up fragments of the fissile shale as it invaded that rock, and finally solidified as a material consisting in some places of more shale than porphyry. This intrusive breccia is well displayed in the Elephant

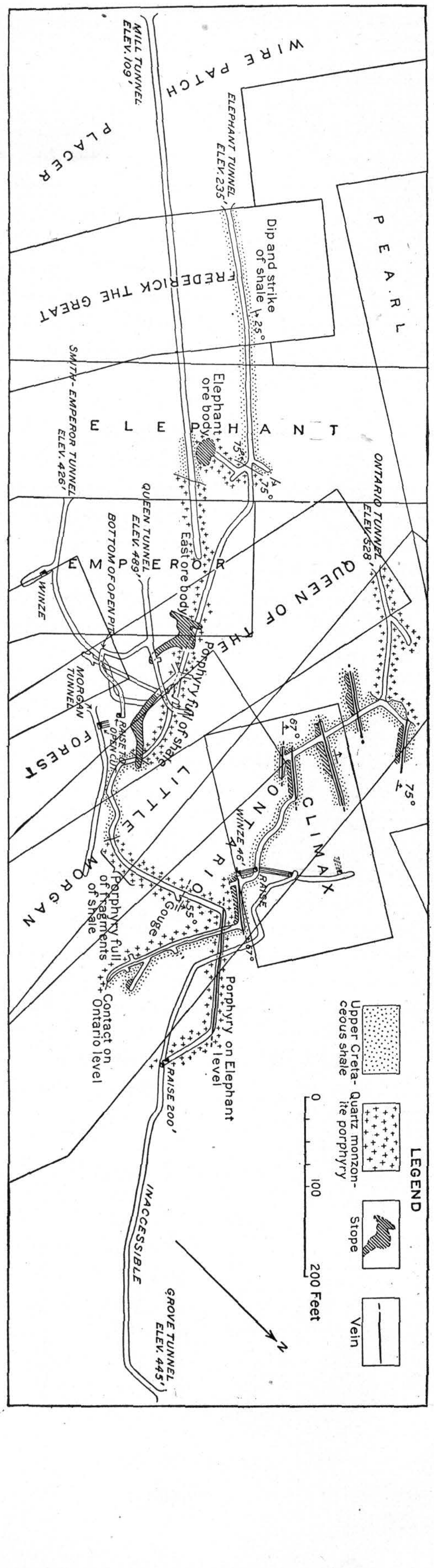


FIGURE 23.—Plan of the principal workings of the Wire Patch and Ontario mines, showing some of the geologic relations of the ore bodies.

tunnel and in the stopes above that level. After passing for 270 feet through shale the tunnel enters porphyry crowded with shale fragments. On the tunnel level this material is not much metallized, but just above is the Elephant ore body, a large irregular mass that is said to have been stoped for over 200 feet eastward and up to the surface. Only a very small part of these stopes could be seen in 1909, and whether they connect with the open pit on the hillside just above the Queen tunnel could not be ascertained. Much of the ore consists of shale fragments surrounded by a shell of pyrite, sphalerite, and galena, the sulphides having been deposited on the surface of the shale by replacement of the porphyry.

After first entering the porphyry, the Elephant tunnel continues in a general east-northeast direction through this rock for about 350 feet and then again reaches shale. For 150 feet from this second contact the porphyry is crowded with shale fragments, and partly in this material, partly in the porphyry above the tunnel, is another irregular ore body, which has been stoped by the present lessees. This stope is under the southwest end of the open cut but, so far as is known, does not connect with it. The two principal ore bodies of the Wire Patch mine thus occur on opposite sides of an irregular porphyry dike, which, where crossed by the Elephant tunnel, is about 350 feet wide. The western or Elephant shoot dips to the east at about 75°, and the eastern shoot apparently dips to the west at about 45°. Ore bodies so irregular in form, however, can not be expected to maintain a definite dip or pitch for any great distance. The hope that the two ore shoots would come together below was influential in determining the driving of the Mill tunnel. This tunnel, after going through shale for 516 feet, entered metallized porphyry containing shale fragments. Apparently the results were not altogether encouraging. The air in the Mill tunnel was too foul in 1909 to permit an examination of this porphyry.

Beyond the east ore body the Elephant tunnel goes through 100 feet of shale and then again into porphyry, within which it follows for 150 feet one of the northeast fissures that were formerly productive of rich gold ore on the Ontario claim. It is to be noted that this part of the tunnel is all in porphyry, whereas the Ontario tunnel, 300 feet higher, is mostly in shale. Not only are the intrusive bodies of porphyry highly irregular in form, but they include, in addition to the numerous small fragments of shale already referred to, some large blocks of shale that are possibly 100 feet or more across, although none is well enough exposed on all sides for satisfactory measurement.

The only place in the Wire Patch mine where the occurrence of the ore could be at all satisfactorily examined in 1909 was in the east stope, about 25 feet above the Elephant tunnel. Here a series of irregular, untimbered connected chambers had been worked out in the porphyry, which at this particular place is not so crowded with shale fragments as in the part of the Elephant stope seen. The ore consists of sericitized porphyry carrying pyrite, sphalerite, galena, and occasionally a little pale-pink carbonate of manganese and iron that may be designated impure rhodochrosite. These minerals in part fill numerous irregular fissures and interstices in the fractured porphyry, but to a considerable extent they have metasomatically replaced that rock, the process working outward from the many fractures. Pyrite is by far the most abundant sulphide, and galena is rather rare, occurring here and there in bunches composed of crystals up to an inch across. Some of the pyrite is as coarsely crystalline as the galena.

The ore is concentrated by jigs and tables to a product that in 1908 was running about 0.9 ounce of gold and 10 ounces of silver to the ton, with 34 per cent of iron and 10 per cent of silica.

CHAPTER XI.

THE FARNCOMB HILL GOLD VEINS.

DISTRIBUTION AND GEOLOGIC ENVIRONMENT.

Deposits of the Farncomb Hill type are not known outside of the area that embraces the northeast slopes of Farncomb and Humbug hills The really important veins have an even more restricted range, being limited to the western part of Farncomb Hill and to an area 2,500 feet long and less than 1,500 feet wide, the southern side of which may be considered as lying generally along the crest of the hill from the Ontario saddle on the west-northwest to the head of Dry Gulch on the south-southeast. If the productive parts of the veins only are taken into account a rectangle 2,500 feet long and about 500 feet wide might be laid out across the fissures so as to include all the pay shoots. The general trend of the veins is nearly northeast. The principal ones recognized from west to east are the Ontario, Key West, Boss No. 2, Boss, McQuery, Reveille, Carpenter, Gold Flake, Graton, Silver (or West Bondholder), Bondholder, and Fountain veins. These fall into two groups, of which the western one, comprising the Ontario, Key West, Boss No. 2, Boss, McQuery, and Reveille veins, is separated by an interval of 700 to 800 feet from the eastern group.

The geologic relations of the veins may best be understood by reference to the general geologic map (Pl. I, in pocket) It will there be seen that a considerable portion of the western part of Farncomb Hill is composed of quartz monzonite porphyry, all of which is more or less altered and weathers with characteristic rough, pitted surfaces. This porphyry is an irregularly shaped mass which connects with a larger body along the crest of Humbug Hill and with some small sheets and dikes. The Farncomb Hill mass is intrusive into dark Upper Cretaceous shale that strikes generally from N. 10° W. to N. 30° W. and dips northeast at an average angle of 30° The porphyry body, as a whole, shows some tendency to conform with the general dip of the shale, but in most places it clearly cuts across the beds and probably somewhere continues almost vertically downward to abyssal depth In other words, it appears to occupy the site of one of the minor conduits that supplied magma for the porphyry intrusions. On the north, the map shows two sharp projections from the mass. The longer and more slender one, extending well down the slope toward Georgia Gulch, is a dike The shorter one is probably merely the upper sloping surface of the main mass, exposed by erosion at the head of American Gulch.

All around the porphyry the shale is thoroughly brecciated and nearly everywhere there intervenes between the solid porphyry and the undisturbed shale a zone of passage from porphyry containing a few fragments of shale to shattered shale cemented by porphyry. This is clearly an intrusional phenomenon and is not a result of brecciation after the solidification of the porphyry. The igneous material caught up the shale fragments or penetrated the interstices between them, and, while still in a molten condition, bound the shattered material together. Nevertheless, the sedimentary rock shows no perceptible crystalline metamorphism, partly because it is not especially calcareous but chiefly, doubtless, because the porphyry magma was intruded at low temperature and solidified with comparative rapidity. This suggests that, although there may have been a direct connection with magmatic sources by a conduit under Farncomb Hill, this conduit could scarcely have been of any great size and could not have afforded egress to large quantities of molten material. The zone of shale fragments is in some places fully 100 feet broad and generally shows some metallization. Prospect pits in it as a rule reveal a little chalcopyrite partly changed to malachite, and the Elephant ore body of the Wire Patch mine is essentially a metallized part of this breccia zone. The shale fragments in the porphyry are in part sharply angular, in part rounded and pebble-like. The rounded ones commonly exhibit a faint superficial concentric banding, showing that some little chemical change has taken place in them close to the porphyry matrix. As a rule the fragments have lost their original nearly black color and are light gray.

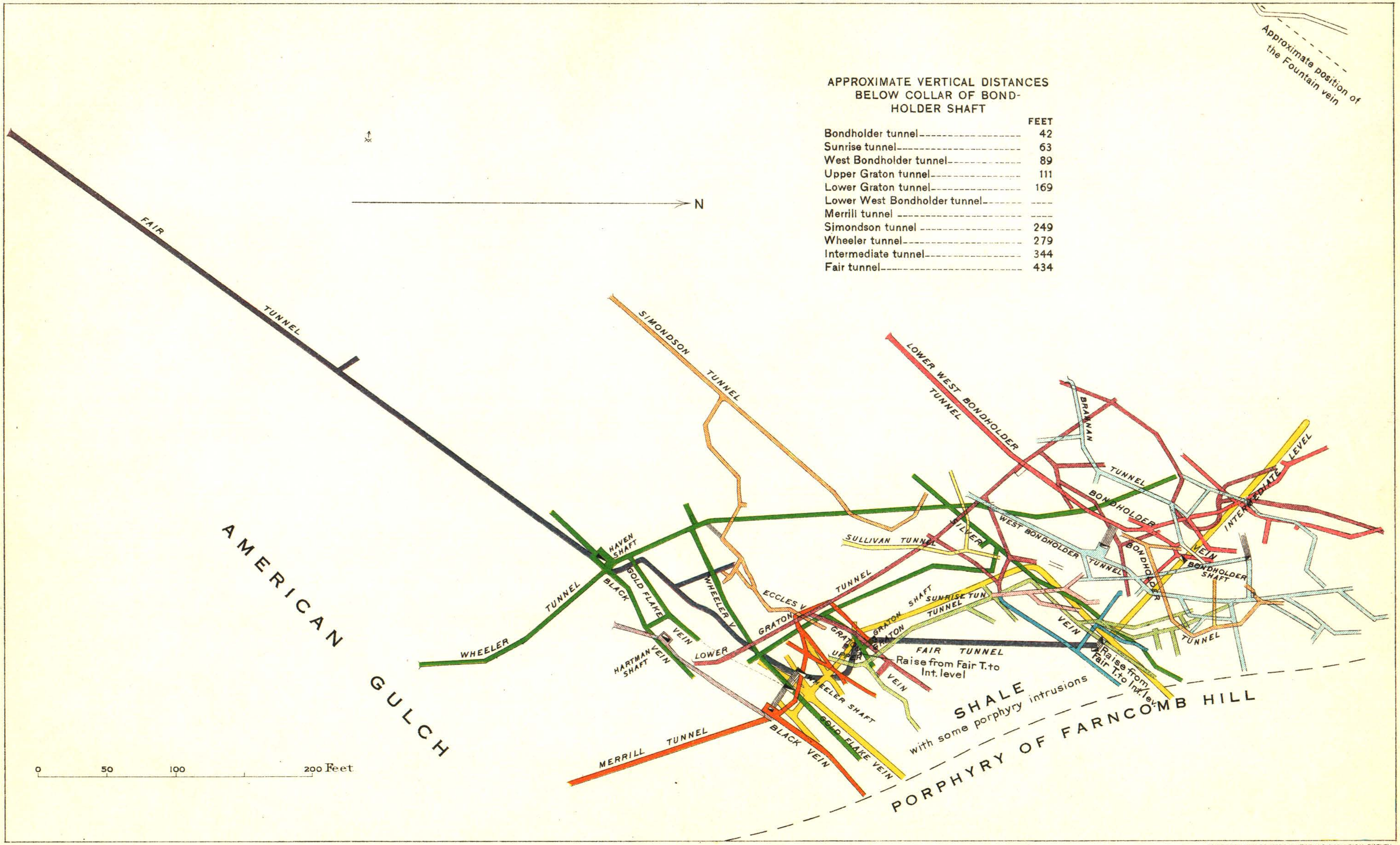
The rich gold veins lie near the porphyry mass on its north side. At the head of Georgia Gulch, in an embayment of shale between the Farncomb and Humbug Hill masses of the porphyry, are the veins of the Ontario, Key West, and Boss group. At the head of American Gulch, lying between the Farncomb Hill porphyry mass on the west and a long, slender dike of monzonite porphyry on the east (see Pl. I, in pocket), are the Gold Flake, Graton, Silver, Bondholder, Fountain, and other veins of the eastern or Wapiti group. It is doubtful whether any important pocket of gold has been found more than 300 feet from the main body of porphyry. On the other hand, although some of the veins unquestionably enter the porphyry, they have never, so far as could be ascertained, proved productive in that mass, although gold has been found in the veins where they traverse some of the relatively thin sheets of porphyry intrusive in the shales. Between the two principal groups of veins there is at least one other vein known, the Kingfisher, which traverses the little tongue of shale that, as shown on Plate I, projects into the porphyry just west of the head of American Gulch. This vein dips northwest, like those of the western group, and shows a few copper stains, but it is not productive.

UNDERGROUND WORKINGS.

Although some shallow shafts, including the Ontario, were sunk on the veins in the early stages of development, it was soon found that adits were more economical and convenient. There are now a large number of adits on the north side of Farncomb Hill (see Pl. XVII, *B*, p. 76), but the workings generally are in poor condition and can only in part be examined. Even where the portals of the tunnels have not caved or been covered by later dumps they are sometimes completely closed by accumulations of ice. It is long, moreover, since any accurate surveying was done in the hill and in the meantime lessees have burrowed here and there until there is little correspondence between present conditions and the latest available plats.

FIGURE 24.—Sketch plan of the lower Key West tunnel, showing character of fissuring.

A part of the old Ontario workings is shown in figure 23 (p. 151), in connection with those of the Wire Patch mine. The Ontario tunnel, although partly filled with ice, could be examined in 1909. It appeared that stoping had been done on five or six small short veins in a body of shale which is bounded on the east and west by porphyry. The Grove tunnel, on the north side of the hill, about 80 feet below the Ontario tunnel and in the neighborhood of 100 feet below the saddle between Farncomb and Humbug hills, is completely closed.



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GENERAL PLAN OF THE PRINCIPAL WORKINGS OF THE WAPITI GROUP EXCLUSIVE OF THOSE ON THE FOUNTAIN VEIN

Based on old surveys. Intermediate level and part of Fair tunnel plotted from pace and compass notes

The Key West vein has been worked through three or four small tunnels of which the lowest, shown in plan in figure 24, is a good example. The upper workings have largely fallen in.

The Boss workings are similar in character and condition to those of the Key West. The upper Boss tunnel enters the hill from the road (see Pl. I, in pocket) and, although it was not entirely closed in 1909, very little information was obtainable in it. Below the road are two or three other tunnels which formerly gave access to the Boss vein, but all are now blocked. Recently some lessees have partly opened one of these so as to reach and work the Reveille vein, which lies southeast of the Boss vein.

The workings of the Wapiti group are all on the American placer claim (also known as Fuller & Greenleaf placer No. 85), which was patented before the existence of the veins was known. They are shown in part in Plate XXX, based on old surveys and far from complete. The workings have a vertical range of about 434 feet from the collar of the old Bondholder shaft to the Fair tunnel. Scarcely any of the tunnels above the Fair can now be entered through their portals. The Fair tunnel, after crosscutting for 750 feet through shale with a few limestone beds and some regular sills of porphyry, reaches the Gold Flake vein; thence it runs nearly south to the Silver vein. On both veins there are raises that connect with an intermediate level 90 feet above the Fair tunnel. On this level is a 200-foot southeast crosscut that passes entirely under the old Bondholder workings. From the Intermediate level access may be had through raises to the Wheeler and Simondson tunnels.

COUNTRY ROCK.

The general country rock of the Farncomb Hill veins is a variety of the Upper Cretaceous shale which is not by any means confined to this hill but may be matched by material from Rocky Point, Summit Gulch, and many other widely scattered localities in the district. It is so dark a gray as ordinarily to be termed black. It is for the most part slightly calcareous but locally grades into material that might be called impure shaly limestone. Where exposed for a short time to the weather, as in the old placer workings of Georgia Gulch, the shale flakes and crumbles, but in underground exposures, out of reach of the weather, it is a fairly hard and firm rock, as may be seen in the Fair tunnel. Miners familiar with Farncomb Hill recognize certain peculiarities in that shale which they regard as possibly gold bearing. In mass it must have a brownish hue rather than the dull grayish black of the normal fresh shale. This tint, as close examination shows, is due to films of iron oxide on fracture planes. The rock favorable for the occurrence of a pocket also breaks readily into small angular fragments and generally presents the appearance that a geologist recognizes as marking an incipient stage of oxidation or weathering. Although the miner may regard it as a distinct variety of shale, the ore-bearing rock is not essentially or primarily different from most of the shale in its vicinity.

Within the shale are sills or sheets of quartz monzonite porphyry, generally from 2 to 20 feet thick, which are probably offshoots from the main porphyry mass. As a rule these are regular and dip with the bedding of the shale, as may be well seen in the long crosscut of the Fair tunnel. Of less common occurrence are small irregular intrusions of monzonite porphyry, one of which is exposed near the northwest part of the Silver vein in the Wheeler tunnel. Both kinds of porphyry are more or less decomposed and neither appears to have metamorphosed the shale at its contacts.

THE VEINS.

The Farncomb Hill veins are remarkable for their small size, being rarely over half an inch wide. Nevertheless, they cut directly across the bedding of the shale and through the porphyry sills without being deflected into the planes of bedding or contact. For such narrow fissures also they are surprisingly regular and persistent. The Gold Flake, one of the strongest of the veins, has been stoped or followed for a length of 300 feet and to a depth of about 450 feet. The Silver vein is known to be almost as persistent as the Gold Flake. At their ends the veins narrow to invisible cracks, some of which are associated with other small, parallel, overlapping veinlets. As a rule also the principal veins are accompanied by smaller, approximately parallel fissures on one or both sides or send out spur veins at small angles. This characteristic is well illustrated by the Key West vein, as shown in figure 24 (p. 154). The Wheeler vein, shown in Plate XXX (p. 154), is a branch from the Gold Flake and the Eccles vein appears to be a similar spur from the Graton vein. The Black vein, which carries gold but not in minable quantities, parallels the Gold Flake vein on its southwest side at a distance of about 20 feet, and nearly every one of the producing veins is associated with similar but less conspicuous veinlets. Here and there the veins are compound, there being two or more parallel veinlets in a total width of 1 or 2 inches. Moreover, where a vein passes from shale into porphyry it may split up into a miniature stringer lode up to 4 inches wide, as is the case with the most northwesterly vein of the Ontario group, shown in figure 23 (p. 151), and as is illustrated also in the generalized section of figure 25.

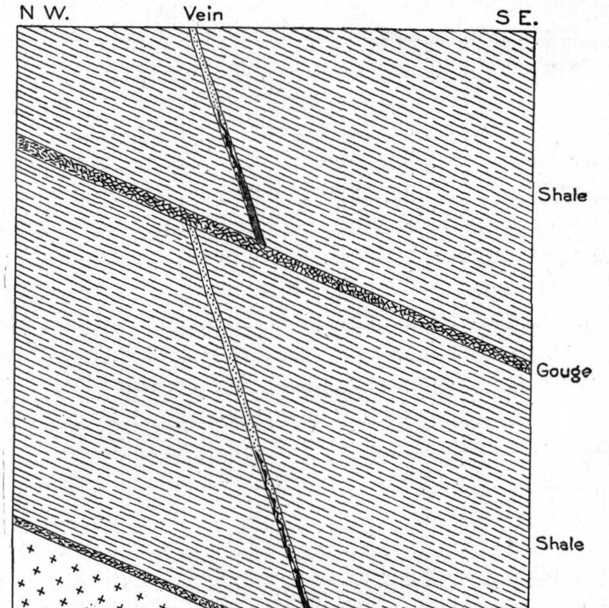


FIGURE 25.—Generalized section of a Farncomb Hill gold vein. The plane of the section is perpendicular to that of the vein, represented as dipping 72° SE. The shale strikes N. 15° W. and dips 35° E. The apparent dip in the section is accordingly less than the true dip. The vein is shown as splitting into stringers in passing through a small porphyry sill. It is slightly displaced by bedding slips accompanied by seams of gouge. The occurrence of the gold pockets (black) is related to these slips and to the porphyry.

The vein fissures were opened with no perceptible faulting of the structures that they traverse. The Gold Flake vein, for example, one of the most persistent in the hill, is well exposed in the Fair tunnel at a place where it passes downward from shale into a porphyry sill. Close examination at this point failed to discover any faulting of the sharp contact between shale and porphyry. Perhaps could all the veins be thoroughly examined it might be found that some occupy fault fissures, but in any case the displacement is probably very slight—a distance of inches rather than feet.

It is as unlikely that fissures so narrow and opened to the accompaniment of so little faulting should continue downward indefinitely as it is that they should continue for miles along the strike. Their character would suggest that as distinct fissures they die out at moderate depth, and the present workings afford evidence that this indeed is probably the fact. In the Fair tunnel, between 400 and 500 feet below the highest workings on the hill, only two of the numerous veins, the Gold Flake and the Silver, have been recognized, although probably some of the others might be found with careful search. On the Intermediate level, 90 feet above the Fair tunnel, the Graton vein has not been identified and a long crosscut run under the old Bondholder workings failed to cut any recognizable representative of the Bondholder veins.

The veins themselves are faulted by numerous slips parallel with the bedding of the shale, or with the contacts of the porphyry sills. Generally these slips are narrow and the displacement effected by them is small. From all that could be learned from miners familiar with the old workings it rarely exceeds 10 feet, and the greatest slip known is about 35 feet. The hanging wall in general appears to have moved down relatively to the footwall, but too little could be seen of the workings in 1909 to establish this as an invariable rule. The effect of such faulting is to give the vein as a whole a steeper attitude than is indicated by its actual angle of dip at any one place. There are a few small faults, also apparently younger than the veins, that cut across the bedding of the shale. A so-called porphyry dike, seen imperfectly in the upper Key West tunnel in 1909, is apparently one of these fault fissures filled with brecciated and recemented shale.

The vein material is generally wholly or partly oxidized and comparatively little can be learned directly of the character of the veins before oxidation. The gangue material, as shown by parts of veins that have escaped oxidation and by comparatively barren stringers accompanying the principal veins, was wholly or chiefly calcite. Sulphides known to have been present in the veins are pyrite, chalcopyrite, sphalerite, and galena. Parts of the Silver vein on the level 90 feet above the Fair tunnel consist of white calcite carrying pyrite, sphalerite, and galena. Other parts are solid, nearly black sphalerite with a little galena and less pyrite. The Reveillé and some of the Ontario veins appear in places to have consisted chiefly of chalcopyrite. The oxidized filling of many of the veins shows copper stains and some of it contains a little unoxidized chalcopyrite. Crystalline native gold has been found from time to time embedded in calcite, sphalerite, or galena. Thus the veins, prior to oxidation, appear to have contained the four sulphides mentioned, in various proportions, accompanied by native gold in a calcite gangue. In the oxidized parts of the veins the calcite and sphalerite have as a rule disappeared, though some of the pyrite, chalcopyrite, and galena may remain. Generally the vein material is more or less spongy or earthy limonite in which occur the masses of native gold described on pages 81–82. Chemical tests on oxidized material from the Silver and Reveille veins show that there is little or no manganese present.

The pockets of native gold for which the veins are exploited are very clearly related to the small faults that dislocate the veins and to the porphyry sills. Prospectors seek and explore the intersections of veins with the bedding slips and with porphyry sills and expect to find the veins practically barren away from these structural features. The workings seen in 1909 indicated that the pockets occur generally above the slips, which, in some places, divide oxidized material above from a calcite vein below. The testimony of those who have worked in the hill, however, is that pockets may lie below as well as above the slips and sills. Gold, moreover, may occur in that part of a vein which crosses a porphyry sill.

The gold is remarkably segregated in these veins. Most of the vein material contains too little of the metal to pay for stoping, but here and there are the famous pockets where a section of the vein 2 or 3 feet in diameter and up to an inch thick may consist of a nearly continuous hackly mass of crystalline gold ramifying through a matrix of limonite. When such a pocket is found the toil of months may be richly repaid by gold to the value of several thousand dollars removable in a few hours and convertible by the miner himself directly into bullion. Although it is now many years since any very rich pocket was found, lessees working the Reveille vein recently took out about $1,000 worth of gold from a section of the vein about 3 feet long and 2 feet broad. This pocket was found close to a little decomposed porphyry dike that cuts the shale. Another pocket, worth from $3,000 to $4,000, was found a few months earlier by the same lessees on the Boss ground.

CHAPTER XII.

VEINS IN THE PRE-CAMBRIAN ROCKS AND OTHER DEPOSITS NOT DESCRIBED IN THE PRECEDING CHAPTERS.

VEINS IN THE PRE-CAMBRIAN ROCKS.

GENERAL FEATURES.

The deposits in the pre-Cambrian crystalline rocks are generally rather narrow fissure veins carrying auriferous pyrite and in some places free gold in a quartzose gangue. Other sulphides occurring with the pyrite are sphalerite, galena, chalcopyrite, and bismuthinite. Not all of these, however, were noted in any one deposit. Veins of this group have not proved of great importance in the vicinity of Breckenridge, and only one, the Laurium, was being worked within the mapped area in 1909.

EXAMPLES AND MINES.

LAURIUM MINE.

As noted in Chapter I (p. 17), the Laurium mine, in Illinois Gulch, was one of the first to be developed in the district and its original owners shipped some lead ore obtained near the surface. After many years of idleness it has recently been reopened by the Blue Flag Mining Co., which in 1909 was concentrating the ore in a 60-ton mill and shipping the concentrates, stated to have a gross value of $32 a ton. The total product of the mine to the end of 1909 is given as about $80,000.

The workings are practically all on one adit level, shown in figure 26. The first vein cut in the adit is called the Porphyry vein; it strikes nearly east and west and dips 75° N. This is a zone, up to 1 foot wide, of small fissures, some of which carry galena, sphalerite, and pyrite. The vein cuts across the foliation of the schists, which here strikes north and dips 75°–80° E. A very little stoping has been done on the vein, which is cut off to the east by a strong fault fissure, as shown in figure 26. This fissure, known as the Lead King vein, although clearly younger than the fissure of the Porphyry vein, carries in its soft gouge and crushed rock considerable disseminated pyrite and some streaks and bunches of sphalerite. This is not merely dragged ore but has apparently been deposited in the fault gouge, although it shows some later crushing by movement along the fissure. This soft vein has been stoped, but the old workings have been closed.

From the Porphyry vein a crosscut through granite and gneiss gives access to the Laurium vein, which in reality is not a single lode but a chain of small veins that pinch out and overlap with considerable variation in strike and dip. Along most of its course on this level the vein is narrow, and in some places it is filled with little more than a film of gouge. At one place, shown in figure 26, it is apparently offset about 75 feet by the Lead King vein or fault. It is not certain, however, that the fissure followed east of the fault is the same as that previously drifted on; the two dip in opposite directions. East of the offset the Laurium vein for 500 feet, as exposed in the drift, contains very little ore. At two places, as shown in figure 26, the vein has been followed to a pinch and then another fissure has been picked up by crosscutting. The main drift continues east for over 100 feet beyond the point shown in figure 26 and here some stoping was in progress in 1909, the stopes at that time being from 2 to 4 feet wide and up to 40 feet high. The ore at this place consists of a much-altered rock, possibly a fine-grained dike, containing disseminated pyrite and traversed by many irregular little stringers of pyrite, sphalerite, galena, and quartz. Under the microscope the rock is seen to be essentially a mixture of quartz and a ferruginous carbonate. This rock contains little indefinite green spots, possibly due to the presence of fuchsite, or chromium mica, a mineral noted by Spurr and Garrey [1] in the wall rock of some of the lodes of the Georgetown quadrangle. The material in the Laurium mine, however, is too obscure for satisfactory determination and may be merely a greenish sericite.

SENATOR MINE.

The Senator mine is 8 or 9 miles south of Breckenridge, on North Star Mountain. A little stoping has been done here in the past and the mine is equipped with a small mill, which has been idle for some years. ~~A general plan of the workings is shown in figure 27.~~ The adits generally follow the vein. The general country rock is fine-grained biotitic gneiss, very irregularly cut by various pegmatites.

The Senator vein strikes N. 5° E. and dips 67° E. Its width varies greatly and attains a maximum of about 4 feet. There is practically no gouge on either wall. The Senator vein is crossed without apparent displacement by the Witch Hazel vein, which strikes nearly east and west and is nearly vertical. This vein resembles the Senator but has a width of 16 feet in one place. Another cross vein, very slightly explored, lies about 270 feet south of the Witch Hazel, as shown in figure 27.

The uppermost tunnel is perched high on the steep slope of the mountain overlooking the Blue, with its portal just below the base of the Cambrian "Sawatch" quartzite, which here rests directly on the crystalline rocks with no intervening conglomerate. These upper workings show that the vein extends into the quartzite, but it is narrower in that rock than below and at the face of the tunnel virtually dies out. Considerable oxidized ore is said to have been taken from the vein in the pre-Cambrian, just under the quartzite.

The veins as exposed in the tunnels below No. 1 are hard, tight, and unoxidized. Their principal constituents are quartz and pyrite, the latter in some places forming nearly the whole of the vein. Associated with these minerals are very subordinate quantities of chalcopyrite, sphalerite, galena, and specularite, with probably some magnetite. According to M. M. Howe, who was doing some work in the mine in 1908, the ore averages from 1.5 to 2 ounces of gold to

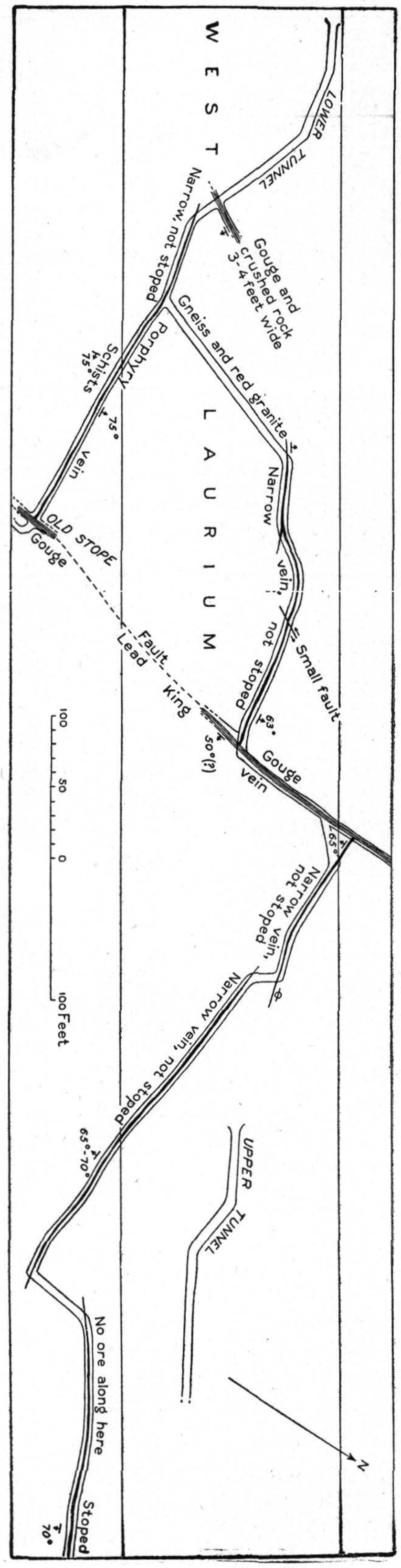


FIGURE 26.—Plan of the principal level of the Laurium mine.

[1] Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 143.

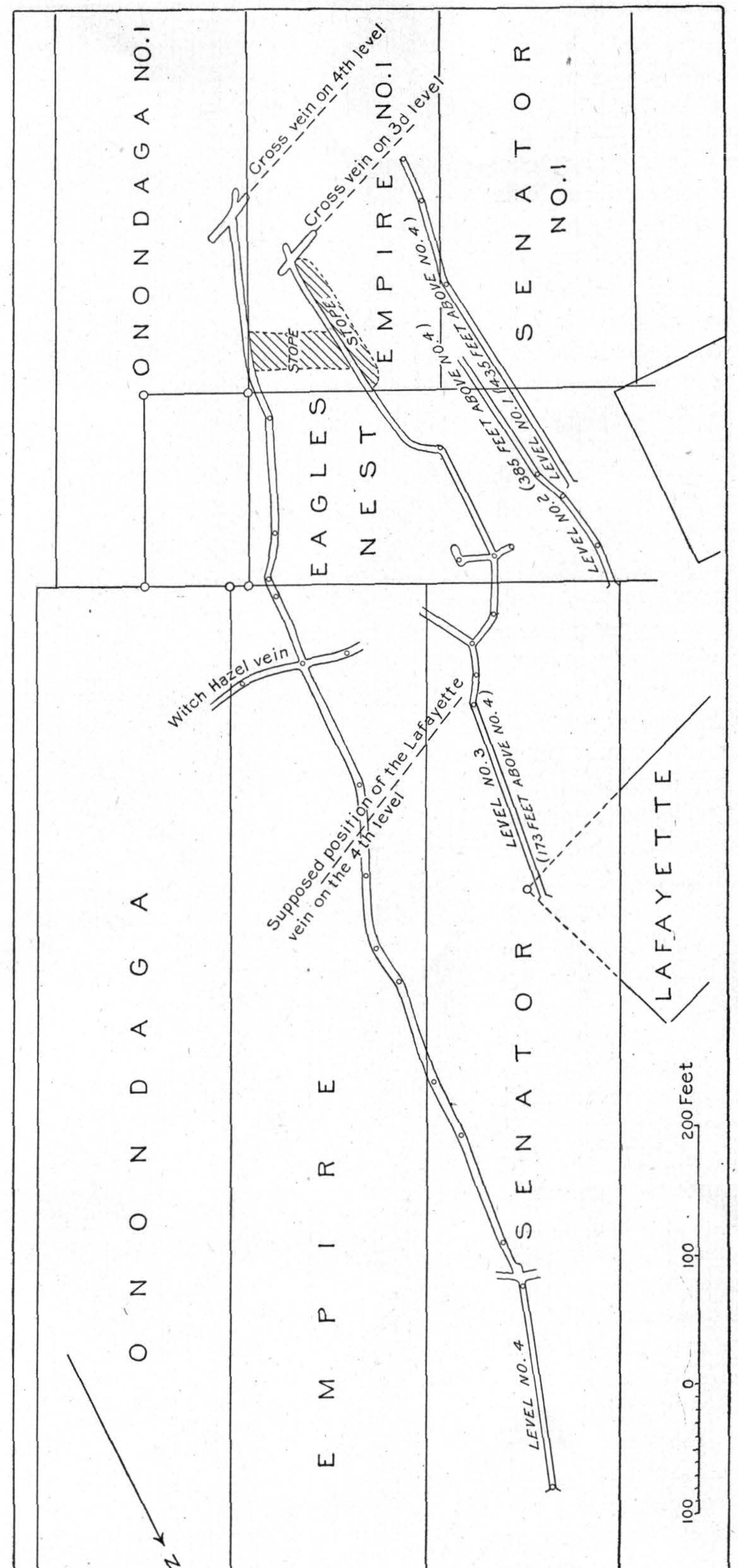


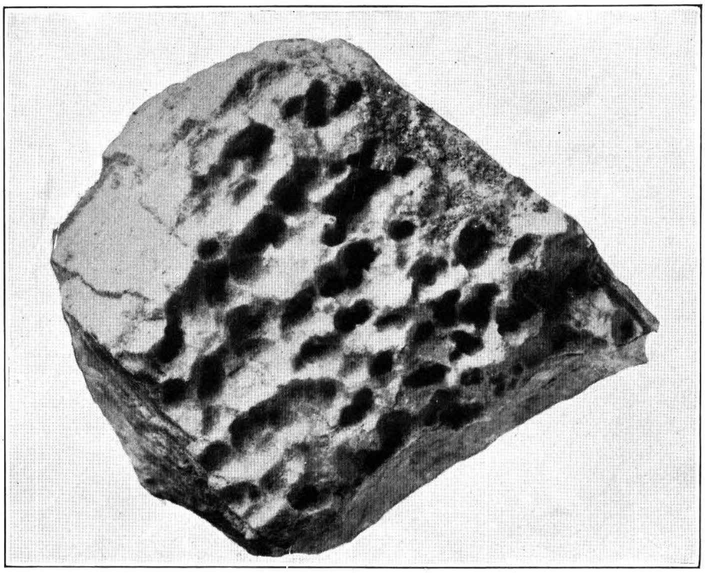
FIGURE 27.—General plan of the underground workings of the Senator mine.

the ton, with a small proportion of silver. This probably refers only to the best shoots, such as were stoped.

ARCTIC MINE.

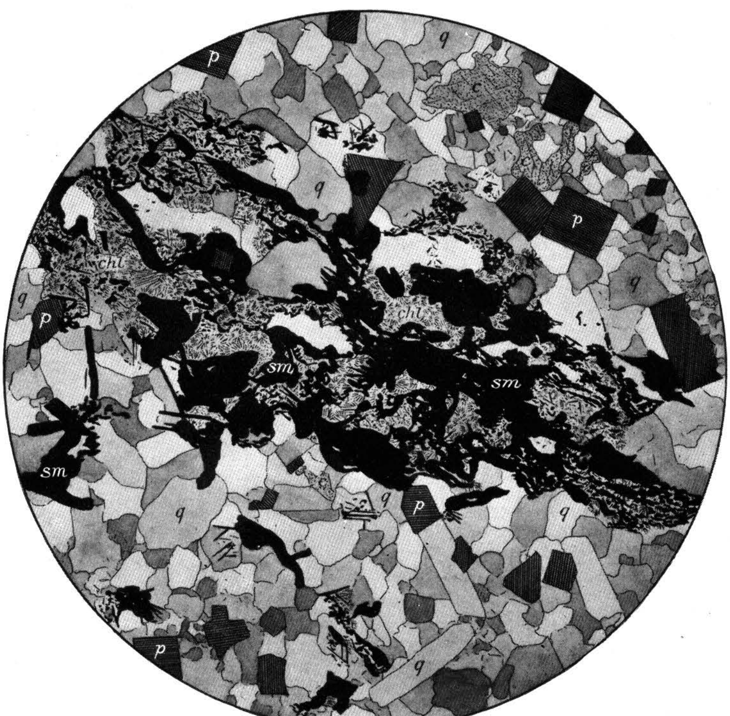
About half a mile west of the Senator mine, in the cliffs south of the lower of the two lakes in which the Blue heads, are the workings of the Arctic mine, credited with a total production of about $50,000, although this is probably exaggerated. The Arctic vein cuts across the foliation of the gneiss, striking N. 15° E. and dipping 75° to 80° E. The vein, however, is very wavy and in places dips west. It consists of solid quartz, up to 1 foot wide, and contains pyrite, chalcopyrite, bismuthinite, and free gold, the last being sometimes found in handsome specimens. There is no gouge and no evidence of movement since the vein was formed. A second vein, known as the Western Star, cuts across the Arctic with a more easterly strike and lower dip. Neither vein appears to fault the other, but more underground work will be necessary to determine the relation of the two veins to each other.

There are four or five tunnels on the Arctic vein, but all except the lowest are little more than cuts in which a face across the vein is exposed to daylight. The lowest tunnel, which is several hundred feet above the lake, was being driven in 1909 to explore the Arctic and Western Star veins but had not opened up ore when visited. A 10-stamp mill had then just been completed and this has since been connected with the workings by an aerial tramway.



A. NATURALLY ETCHED SURFACE OF DAKOTA QUARTZITE.

Natural size. See page 37.



B. ORE FROM THE SENATOR MINE, NEAR THE HEAD OF BLUE RIVER.

Nicols crossed. X 20. Constituents are quartz (*q*), calcite (*c*), chlorite (*chl*), specularite and magnetite (*sm*), and pyrite (*p*). Drawn with camera lucida. Semidiagrammatic See page 159.

LING MINE.

The Ling mine is a short distance west of the Arctic and is similarly situated. It has been worked intermittently by lessees for many years in a small way and has produced a little good gold ore. No examination of it was made.

BLANKET DEPOSITS OF GIBSON AND SHOCK HILLS.

The deposits next to be noticed are of a kind to which the miners generally throughout Colorado refer as "contacts." The term as applied to ore bodies was first used at Leadville, where the irregular sheets of ore were found to lie near the contact between limestone and porphyry and where accordingly there was more reason behind its original application than can be found for its present indiscriminate use for any flat-lying deposit in bedded rocks.

Deposits formed by metasomatic replacement of certain beds in the "Wyoming" and Dakota formations have in the past contributed to the yield of the district. On Gibson Hill the Kellogg and Sultana were the chief producers, and on Shock Hill the Iron Mask was the leading mine. On Gibson Hill, in the Dakota area, there appear to be at least two horizons at which ore deposition has taken place. Nothing whatever can now be seen of these deposits. They yielded oxidized or partly oxidized silver-lead ores of the general character illustrated by the analysis of ore from the Kellogg mine given in the table on page 108.

At the west base of Gibson Hill, close to the Blue, are the tunnels of the Sultana and Fox Hills mines, in the red micaceous grits and shales of the "Wyoming" formation, which dip gently east, at angles up to 20°, and are stepped down to the west by small normal faults. There are two sheets of ore about 5 feet apart and up to a foot or two in thickness. The ore is generally pyritic, but the Sultana is known to have shipped considerable partly oxidized lead ore. Some of the pyritic ore apparently was also stoped, but it must have been of very low grade. The workings of these mines are only a few feet below the bottoms of the old bench-gravel placers and are in bad condition, being for the most part closed. There was no opportunity to study the details of the replacement of the beds by ore.

In Shock Hill the Iron Mask ore is said to have occurred above and below a sheet of porphyry. Its general composition is given on page 108. In some places the carbonate ore was accompanied by much free sulphur, as described on page 81. Nothing whatever could be seen of the ore bodies in 1909.

The dump of the Finding shaft, on the top of Shock Hill, shows some massive sphalerite and abundant massive pyrite, which presumably came from some blanket deposit in the Dakota or "Wyoming" beds. Evidently the material was not worth stoping.

GOLD-SILVER DEPOSITS IN THE DAKOTA QUARTZITE.

At a few places, especially on Shock Hill and Little Mountain, oxidized gold-silver ores have been found at slight depth in the fissured quartzite. No large bodies of ore or persistent veins are known in this group of deposits. The gold and silver are either distributed rather generally along the many small irregular fractures in the little quartzite or segregated at a few favorable spots into pockets of exceptionally rich ore, such as was found in the Germania workings on Little Mountain.

In Little Mountain the quartzite, with intercalated beds of gray shale, dips generally a little west of south at angles of from 30° to 50° and is cut by fissures trending from north to northeast. Some ore has been found in these fissures, but more has come from seams parallel or nearly so to the bedding of the quartzite or from small bunchy pockets.

The most important workings in Little Mountain are those connected with the Germania tunnel (fig. 28), but these are in bad condition and only in part accessible. The tunnel enters the west base of the hill close to the river and runs northeast for about 300 feet through bowlder till and then through about 140 feet of much-disturbed black shale, quartzite, and monzonite porphyry. The structure of these rocks can not be determined from the present exposures in the tunnel. From the main tunnel (fig. 28) a drift turns north on a strong zone of fissuring which dips about 55° W. The rocks along this fissure are crushed and exposures in the drift give no hint of their general structure. At the winze shown in figure 28 a seam of ore was found in hard massive quartzite which was stoped up an incline, as shown. This ore is said to have been of good grade, but the body evidently was small. Its general dip was to the south at about

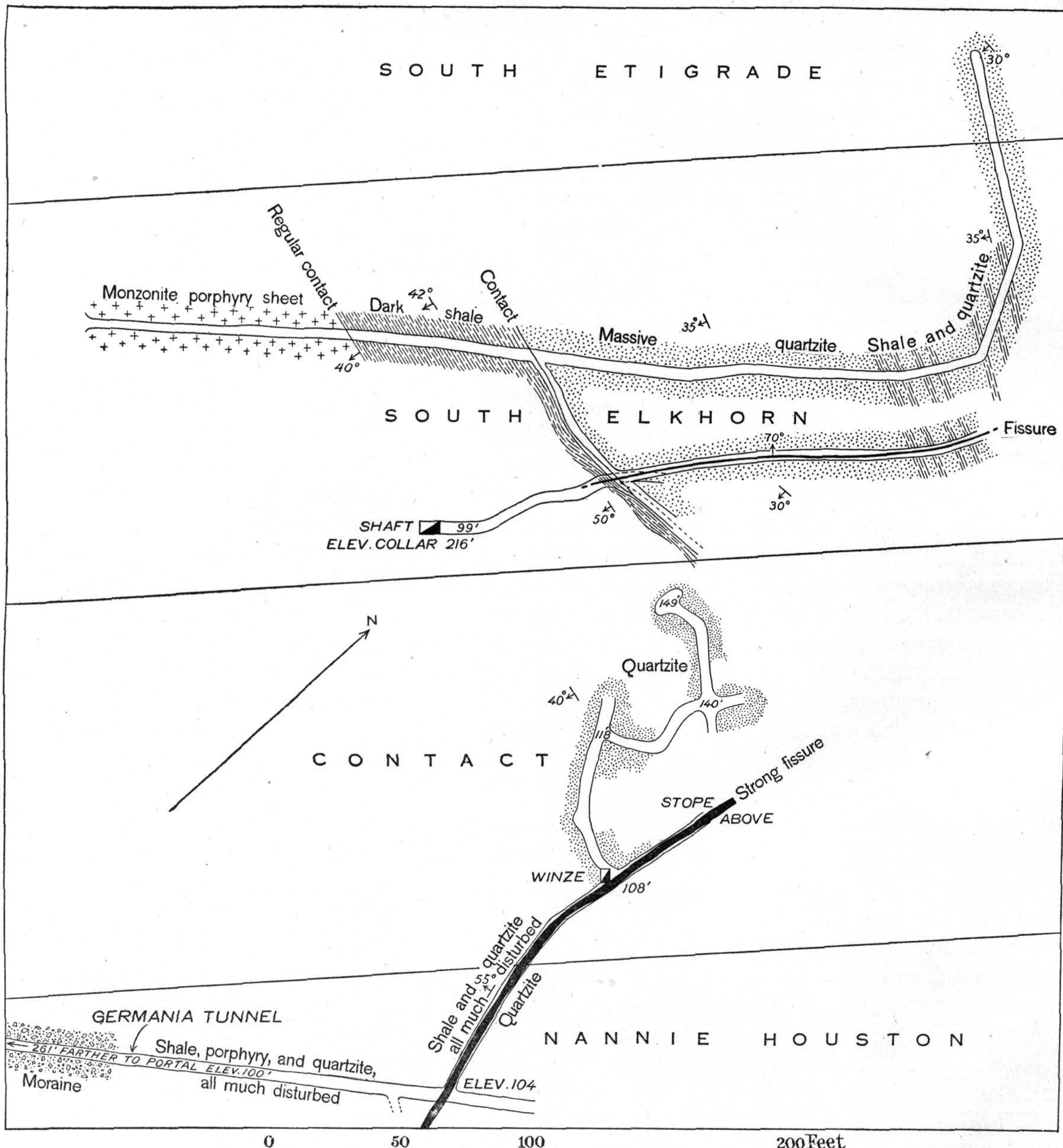


FIGURE 28.—Plan of the Germania and South Elkhorn tunnels in Little Mountain.

28°, whereas the dip of the quartzite is about 40°. The quartzite has been irregularly fractured along a plane lying at a little lower angle than the bedding, and the small fissures and interstitial spaces, some of them enlarged by solution, have been coated with quartz druses and are filled with a porous rusty material that is chiefly limonite. This material, which in places carries enough gold and silver to constitute rich ore, is probably an oxidation product of pyrite.

The richest bunch of ore ever found in the quartzite of Little Mountain lay within 10 feet of the surface in the footwall of the strong fissure which is cut in the Germania tunnel and on whose hanging-wall side was the pay shoot that has just been described. A little flat seam of limonite that was followed into the footwall of this fissure was found to expand into an ore body which, as shown in figure 29, turned down to the east with the bedding of the quartzite. This mass was about 20 feet in diameter and up to 6 feet thick. Around its edge the ore graded into spongy limonite of no value. The ore itself differed little from this material in appearance, being a very porous mixture of limonite and silica which carried gold and much silver. The silver was for the most part probably native or in the form of cerargyrite, but Thomas West, who discovered the pocket, reports that there was also some "sulphurets" of silver—possibly argentite. A few feet southeast of the ore body the quartzite is cut by monzonite porphyry; the ore thus accumulated in an angle between the fissure and the porphyry.

The South Elkhorn tunnel, shown in figure 28, northwest of the Germania tunnel, cuts porphyry, shale, and quartzite, the distribution of these rocks being indicated in the illustration. There is a drift on a fault fissure which strikes northeast and dips 70° NW. The throw of the fault has not been determined, the rock on each side being generally the same—quartzite and some shale. The fissure apparently contains no ore. A little north of this tunnel and higher up the hill, probably on the South Etigrade claim, is another tunnel on a similar fissure also dipping 70° NW. Oxidized ore to the value of $10,000 is said to have been stoped from this fissure between the tunnel and the surface. The country rock is quartzite.

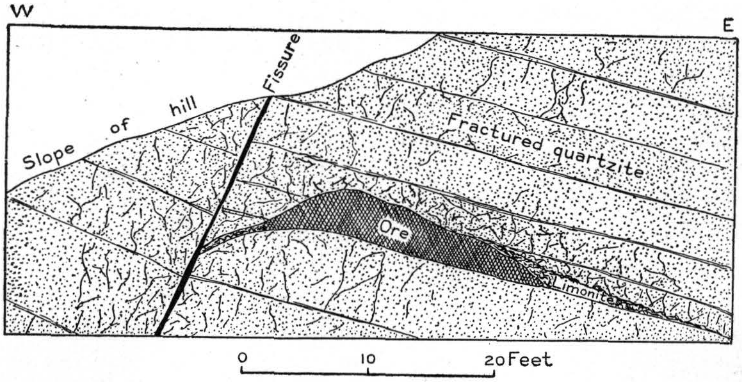


FIGURE 29.—Sketch cross section showing mode of occurrence of a rich pocket of oxidized gold-silver ore in the quartzite of Little Mountain.

The composition of some of the ore from Little Mountain may be seen from the table on page 108.

The gold-silver ore in the quartzite of Shock Hill appears to have been generally similar in occurrence to that in Little Mountain—superficial, pockety accumulations of oxidized ore in the intricately fractured brittle rock. Nothing, however, could be seen in 1909 of the old Brooks-Snider and other workings in the hill. The mill appears to have been supplied by burrowing unsystematically after small streaks and bunches of ore. A part of the quartzite débris was washed by hydraulic means.

On the north side of Illinois Gulch, just east of the Washington mine, the Dakota quartzite, here much shattered, has also been washed by monitors or giants for the gold contained in its crevices.

All of the ore found in the quartzite in deposits of this type is apparently the result of concentration and enrichment by the action of oxidizing waters from the surface upon bunches and small stringers of auriferous and argentiferous pyrite. Some of this pyrite evidently contained a little copper, probably as chalcopyrite, and the abundant silver in such bodies of ore as those found in Little Mountain suggests the former presence of some galena also.

CHAPTER XIII.

SOME ADDITIONAL FEATURES OF THE DEPOSITS AS A WHOLE AND THEIR BEARING ON ORE GENESIS.

PARAGENESIS OF THE ORE-FORMING MINERALS.

The ores of the Breckenridge district, owing to their lack of banding, show only obscure traces of sequence in the deposition of their constituent minerals. In general, the sulphides are irregularly aggregated in a way that at first sight suggests the essentially contemporaneous deposition of all. There is neither uniform occurrence of one sulphide as a crust on others nor any traversing of older constituents by veinlets of younger ones. Nevertheless, although such indubitable evidence of successive depositions is lacking, close inspection of any representative face of ore shows that the sulphide minerals are not all strictly contemporaneous. In ore such as that of the Wellington mine the formation of galena, to a large extent at least, followed the deposition of pyrite and sphalerite. In a general way this is indicated by a tendency on the part of the galena to occur in bunches having a central cavity or vug lined with the free faces of large crystals. There is a tendency also for the galena to segregate in the middle portion of a vein rather than along its walls. The fact that much of the galena is younger than much of the pyrite and sphalerite is determinable in a more particular way from small specimens of the ore. One of these, for example, in the cabinet of Mr. B. S. Revett, shows a coarse aggregate of pyrite and dark sphalerite upon which have grown large cubes of galena whose faces are dusted with a second generation of small sphalerite crystals. Many other specimens collected in the mine in 1909 show the same relation between the galena and the older pyrite and sphalerite, although the younger sphalerite crystals are not common. No evidence that the development of pyrite and sphalerite on an important scale followed the deposition of galena was obtained from the Wellington mine, although, on the other hand, many specimens are inconclusive on this point or show an aggregation of the three minerals, such as may have resulted from contemporaneous growth. In the Wellington veins the siderite (or a related ferruginous carbonate) is younger than the important sulphides, as shown by its incrusting them or running through them as veins. In some places the carbonate contains a little pyrite in small crystals. A little barite noted in the Wellington ore apparently belongs to the very latest period of deposition.

In the Sallie Barber vein the deposition of the principal sulphide constituents, sphalerite and pyrite, was followed by a second and commercially unimportant generation of lighter-colored sphalerite and of pyrite. The growth of these was succeeded and partly accompanied by the deposition of siderite. This in turn was followed by the formation of a little calcite.

It appears that for the veins of the zinc-lead-silver-gold series the general sequence of deposition was (1) pyrite and sphalerite with probably some galena, (2) galena, (3) siderite (or other iron-bearing carbonate) with small quantities of pyrite and sphalerite, and (4) calcite or barite (rare and nowhere abundant). While the foregoing represents the general order of crystallization, there was not an altogether rigid adherence to it. Probably one stage overlapped upon another. Moreover, there is fair evidence that after the first sulphides were found these were modified in many indistinguishable epochs by fracturing followed by solution and redeposition of sulphides. Thus the parts of the veins now worked are probably the result of a complex process of growth during which fracturing, solution, and deposition were many times repeated and in which ordinary ground water was an active agent.

With reference to the stockworks and veins of the gold-silver-lead series the data for establishing a sequence of mineralogical deposition are wanting. Presumably, however, the order of deposition was generally similar to that deduced for the zinc-lead-silver-gold veins.

Little is known of the nature of the Farncomb Hill veins prior to their oxidation. Specimens show that gold has crystallized with galena, sphalerite, and calcite, but the large masses of gold found have all been in oxidized material.

The auriferous veins in the pre-Cambrian rocks show no recognizable depositional order in the aggregation of their constituents, so far as could be seen in the workings examined in 1908 and 1909. Of the original mineralogical character of the blanket deposits little can now be learned.

EFFECTS OF VARIOUS WALL ROCKS ON ORE DEPOSITION.

That the character of the ore deposits depends to an important extent on the kind of rock inclosing them is apparent after even a cursory examination of the district. The blanket deposits are found only in the bedded rocks of the Dakota and "Wyoming" formations; certain pockety accumulations of oxidized gold-silver ore are characteristically associated with the hard quartzitic beds of the Dakota; the veins of the zinc-lead-silver-gold series are all in or near monzonite porphyry, while the stockworks and veins of the gold-silver-lead series are all intimately associated with the quartz monzonite porphyry; finally, the gold-bearing veins of Farncomb Hill suggest a more than accidental connection between them and the Upper Cretaceous shale.

It is in some cases difficult or impossible to determine what significance should be attached to a given association of a certain type of ore body with a particular rock. The question is likely to arise, especially if the kind of deposit under discussion is found only in one locality, whether the character of deposition would have been essentially different had another country rock happened to be prevalent at that place. Thus it may be asked, Do the characteristic features of the Farncomb Hill gold veins depend on the shale; or would they have been essentially the same were the hill all porphyry? If similar deposits were known elsewhere in the district and were invariably associated with the shale, the supposition of genetic connection would be manifestly much strengthened. As it is, the single group of these veins must be closely examined to ascertain whether the shale has played a dominant or negligible part in their formation. Study of them shows that the physical properties of the shale have had a controlling influence on fissuring and on the deposition or concentration of the gold. Thus the finely laminated but firm and homogeneous shale parted under stress in such a way as to be traversed by remarkably sharp, narrow, and regular fissures which in proportion to their widths are unusually persistent. Had the rock all been porphyry the stresses would probably have been relieved by more irregular fissuring, as may be seen in the sills of Farncomb Hill and in the deposits of the Jessie type. The lamination of the shale permitted the minor slips along bedding planes, which dislocated the little veins and in connection with the regular original fissures provided almost ideal conditions for the concentration of the gold in the course of oxidation and erosion. How far the chemical composition of the shale aided in precipitating the gold is doubtful. The shale contains some finely divided carbonaceous material to which, with abundant minute crystals of pyrite and a little magnetite, its dark color is due. The rock, however, when pulverized and heated in a test tube yields no distinct odor and no distillate of volatile hydrocarbons. Heated in an open tube the powder gives off sulphur dioxide from the pyrite, which is not visible in fragments of the shale but can readily be separated from the powdered rock by panning. Undoubtedly the oxidation of these disseminated dustlike crystals of pyrite had much to do with producing the brown tint which the miners recognize as favorable to the occurrence of a gold pocket. The carbonaceous and pyritic particles in the shale probably had some influence also in precipitating the gold either from the original metallizing solutions or from descending waters of meteoric derivation.

To the deposition of some ores, on the other hand, the shale appears to be decidedly unfavorable. The veins of the zinc-lead-silver-gold series, so far as can be determined from underground workings now open and from records, become of little or no value when they pass wholly into shale. There was, however, no good opportunity in 1909 to study this change in detail. The same rule holds good with respect to the gold-silver-lead group and is well illustrated in the

Jessie and Hamilton mines. In those mines wherever the shale is reached the ore ends within a few feet. The Whitehead stope (see fig. 18, p. 145), in places fully 15 feet wide, was carried for a few feet across the contact into the shale, but the ore was found to change into a network of small pyrite stringers containing very little gold. These become less numerous as they extend into the shale, and finally the face of the drift shows only one fairly regular stringer of calcite, less than an inch wide, containing a little pyrite. The near-by shale also contains disseminated pyrite. Thus the wide zone of fracturing in the porphyry diminishes to a little veinlet not unlike some of the Farncomb Hill veins below their enriched zone. The reason for the superiority of the porphyries over the shale as a country rock for ores of low gold tenor containing galena and sphalerite is not altogether clear. Bulk of sulphide material is important in deposits of these types, and the porphyries probably have an advantage over the shale in their greater rigidity and brittleness, which favors the opening of larger spaces than would be produced by an equal stress applied to the shale. Then, too, the porphyries, especially when much fractured or crushed, appear to be more susceptible than the shale to metasomatic replacement. These relations are suggestive of those observed in the Cœur d'Alene district in Idaho,[1] where the great silver-lead deposits, due largely to metasomatism subsequent to fissuring, are in brittle sericitic quartzites, whereas the smaller gold-bearing veins are in dark argillaceous slates.

No satisfactory explanation has been found for the association of the two principal varieties of porphyry with different types of ore deposit—types which appear in fact to be more distinct than are the two porphyries themselves. Why should the more calcic monzonite porphyry be accompanied by ores generally poor in gold but rich in galena and sphalerite, while in the quartz monzonite porphyry gold and silver are the important constituents, galena and sphalerite being accessory? If the difference in the ores were a matter of locality rather than of porphyry, we should expect to find the Wire Patch ore bodies similar in character to those of the Wellington mine, instead of more nearly resembling, as they do, those of the Jessie mine. Apparently there is sufficient physical difference in the two rocks to favor the production of comparatively simple and large fissures in the monzonite porphyry and complex zones of small fissures in the quartz monzonite porphyry. Partly in consequence of this difference the veins of the quartz monzonite porphyry have been more readily acted upon by descending waters, and there has been a greater concentration of galena in their upper portions. It has been shown also that the monzonite porphyry is probably a little older than the quartz monzonite porphyry. Accordingly the former rock may have been fissured when the latter was intruded. Thus the stronger and simpler fissuring of the monzonite porphyry may be a consequence of more vigorous and long-continued stresses in that rock than in the quartz monzonite porphyry. This perhaps is in part the explanation of the failure of the veins in the Wellington mine to maintain their regular character where they enter the quartz monzonite porphyry in the eastern part of the mine.

VERTICAL VARIATIONS IN THE ORES.

To an important extent in this district, changes in country rock have caused abrupt changes in the character of a deposit along vertical lines. Such departures from uniformity have been discussed in the preceding section. Of present concern are the more gradual transitions which may occur without any corresponding variation in the inclosing rocks and apparently quite independently of wall-rock influences.

The vertical range through which the Breckenridge ores can be studied is, as already amply shown, exceedingly short. Direct observation is at present restricted to depths of less than 350 feet. For such data as bear on successive downward changes in the ores it is necessary to depend almost entirely on the history of the mines. The records are most of them significantly alike. For instance, the Lucky, Minnie, Ella, and Cincinnati mines, in the monzonite porphyry of Mineral Hill, all had some galena or cerusite ore of shipping grade near the surface, but at various depths, not accurately ascertainable though probably nowhere exceeding 300 feet, this ore gave place to more pyritic material. Some of this was milled for a time, but ultimately

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

the ore ceased to yield a profit under methods then in vogue, and work was abandoned. The country rock of these mines is generally uniform and presents no variation that can account for the downward decrease in the tenor of the ore.

The Laurium mine originally shipped an argentiferous lead ore, but now yields a concentrating gold-silver ore from a level between 200 and 300 feet below the old surface workings. In the Wire Patch, Jessie, Hamilton, and Cashier mines galena appears to have been more abundant near the surface than in the deeper workings. The lower tunnel of the Country Boy mine shows hardly any galena, although this sulphide was abundant in some of the ore from the upper workings. The Sallie Barber mine had some galena and considerable cerusite above the 240-foot level, but below that level the quantity of lead in the ore is negligible. The Wellington mine, it is true, shows abundant galena on the Oro adit level, the deepest workings now open, but the proportion of pyrite and sphalerite is apparently greater on the whole than in the upper levels. The deepest ore seen in 1909, at the east end of the Oro level and perhaps 350 feet from the surface, was sphalerite, containing 38 per cent of zinc and 1 per cent of lead. Unfortunately, nothing could be learned at first hand of the ore in the levels connecting with the Oro shaft below the present main adit. Probably the galena extends lower here than it does far in under Mineral Hill, and it is known that some good lead ore came from stopes worked through the shaft. In these deeper workings also the country rock changes and shale, generally an unfavorable rock for the occurrence of lead-zinc ores, appears in places under the porphyry.

Doubtless if complete records were obtainable of all the idle or abandoned mines, they would largely be a repetition of the same story—partly oxidized lead ores near the surface and sphaleritic or pyritic ores below. Even the imperfect data now available establish without much question the limitation of the lead ores to a zone ranging from 200 to 300 feet deep and corresponding roughly to the present strongly accidented topography. There may, of course, be exceptions to this apparent rule; the underground workings are not extensive enough to afford a basis for sweeping assertion. The statement made, moreover, is far from implying that there is no galena below a depth of 300 feet; but all available evidence indicates that in this district 300 feet, or perhaps more safely 400 feet, is the limiting depth for the occurrence of considerable bodies of essentially galena ore as opposed to sphaleritic or pyritic ores.

This superficial accumulation of lead ores appears to be explainable by only one process—that of downward enrichment in connection with the erosion and oxidation of the upper parts of the veins. To suppose it a feature of the original deposition of the ores would require the untenable correlative supposition that the topography of the district has not changed since the veins were first filled. The placers, with their nuggets of gold, sphalerite, and galena, are clear evidence to the contrary, and if it were possible to restore the landscape as it was when deposition of the ores began, one familiar with the hills and valleys of to-day would doubtless find himself in strange surroundings. The explanation that the concentration of the lead with its associated silver is the result of enrichment is consistent with the close relationship of the lead zone with oxidation and with the general evidence already presented that the galena in the veins is, in great part at least, younger than the pyrite and sphalerite. Consideration of the process or mode of enrichment may naturally be taken up in connection with the subject of oxidation.

OXIDATION AND ENRICHMENT.

GROUND WATER.

The present surface of the ground water in this district is probably very irregular, although less so than it was before the hills were pierced by adits. The heavy winter snow, which in places lingers into the autumn, and the copious summer showers saturate all rocks except those on slopes so steep that the water is rapidly drained into near-by ravines. Along the main stream valleys the water level is practically at the surface of the ground. At the Sallie Barber shaft, situated on a sharp ridge about 600 feet above French Creek, the original water level was apparently at about 200 feet depth. In the Juventa shaft, similarly situated, on the north side of French Gulch, oxidation is said to have reached a depth of 200 feet, which presumably was about the water level. Beyond the additional facts that more or less water issues from nearly all tunnels not choked with ice, and that most of the abandoned shafts in the district, no matter at what elevation, provided that they are not directly drained by adits, are partly filled with water, the underground workings supply very little information regarding the original water surface.

OXIDATION OF LEAD-ZINC ORES.

So far as can be determined from rather scanty data general oxidation of the ores rarely extends below a depth of about 200 feet and some residual galena may persist nearly to the surface. On the other hand, incipient oxidation, as shown by the development of a little spongy impure smithsonite, may penetrate to a depth of 350 feet. Oxidation goes deeper in the permeable ores composed chiefly of sulphides than in siliceous veins such as occur in the pre-Cambrian rocks at the headwaters of the Blue.

The usual product of oxidation in all but the essentially auriferous veins is a porous or earthy mixture of limonite and cerusite with more or less siliceous and aluminous impurity. Some of the best ore is a soft, heavy, claylike material, consisting chiefly of lead carbonate, and probably lead sulphate also, with a considerable proportion of silver. The cerusite is in few places well crystallized, and the silver is rarely visible. Wire silver was found, however, in the oxidized ore of the Juventa mine, near Lincoln, and in the old Liberty tunnel of the Wellington group.

A notable feature of the oxidized ores is their general high content of lead and silver as compared with the sulphides beneath. In some mines this difference was so great that their owners after extracting ore profitably to the base of the oxidized zone found the sulphides of so low a grade that work was abandoned. Here and there the oxidized ores also show a noteworthy concentration of gold even where the sulphide ores below contain only negligible quantities of that metal. Thus the Helen mine, on the south side of French Gulch, had some gold ore near the surface, although the latest and deepest workings have exposed nothing but a little sphaleritic zinc ore. In the Juventa mine, which produced some good oxidized ore to a depth of 200 feet and was then abandoned, gold is said to have been found in the form of wires suggestive of those from the auriferous veins of Farncomb Hill.

The occurrence of native sulphur in the oxidized ore of the Iron Mask mine has been noted on page 81. This is probably not an infrequent product of the reduction of ferric sulphate to the ferrous form by coming into contact with sulphides, and it is found occasionally in other districts, usually with partly oxidized ores; but as a rule the native element is oxidized to sulphuric acid during subsequent stages of weathering. In some way not known the sulphur in the Iron Mask was protected from the usual oxidation.

In ores consisting essentially of pyrite, sphalerite, and galena exposed to weathering, the galena, owing to the comparatively strong chemical bond between lead and sulphur, proves most resistant to the oxidizing agencies, and in this district, as in most others where the climate is not too dry and erosion is fairly vigorous, residual lumps of galena may remain close to the surface, although the other sulphides have been entirely decomposed. Sphalerite, according to some writers,[1] is supposed to be more resistant than galena and the other common metallic sulphides, but this does not accord with the usual experience in the field.

At Breckenridge the oxidized ores rarely contain any sphalerite and below the zone of general oxidation this mineral is one of the first to part with its sulphur to form smithsonite.

SULPHIDE ENRICHMENT OF LEAD-ZINC ORES.

The absence of sphalerite from the oxidized ore is probably not altogether or even largely a matter of direct weathering. Apparently much of the sphalerite was removed from the upper parts of the veins and was replaced by galena in advance of the slowly descending belt of oxidation in the manner so clearly described by Van Hise.[2] Thus three factors cooperate to

[1] See, for instance, Emmens, S. H., The chemistry of gossan: Eng. and Min. Jour., 1892, pp. 582-583; also Beck, Richard, Erzlagerstätten, 3d ed., Berlin, 1909, vol. 2, pp. 314, 328. Beck gives Emmens's arrangement of the sulphides in order of supposed affinity for sulphur and also presents Van Hise's views, which involve a stronger affinity between lead and sulphur than between zinc and sulphur.

[2] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 1148-1151.

concentrate the lead in the upper parts of the veins—(1) the resistance of the galena to oxidation, (2) the comparative insolubility of the sulphate and carbonate of lead, and (3) the readiness with which such lead as may go into solution in the form of sulphate or carbonate is acted on by sphalerite or pyrite and precipitated again as galena immediately below the zone in which oxidation is paramount. It is believed that a large proportion of the galena in the Breckenridge ores is the result of this downward concentration by atmospheric water, which, after percolating with comparative rapidity through the oxidized zone to the local ground-water level, thence moved more deliberately down through the sulphides, to emerge finally along the bottoms of the main valleys.

The zinc abstracted from the oxidized zone should theoretically be carried down also and deposited as sphalerite by reaction with pyrite at a depth generally greater than that at which galena accumulates. Whether any large part of the sphalerite in the Breckenridge veins has been thus secondarily deposited is not clearly determinable from existing workings, although, as shown on page 164, there is certainly some sphalerite much younger than other.

A large part of the iron originally present as pyrite remains in the oxidized ore as limonite, but some is doubtless carried down as bicarbonate, and together with the carbonates of calcium, magnesium, and manganese is deposited as an impure siderite in veinlets traversing the sulphide ores or as the lining of vugs in these ores. Additional iron is taken up by the ground water in any reaction involving the replacement of pyrite by sphalerite or galena, so that any of this water issuing as springs after performing its work of enrichment is likely to be strongly ferruginous, as is that of a spring near the Puzzle and Ouray mines. The iron-bearing water that flows from some old tunnels may have obtained some of its iron in this way, although probably most of it is merely the result of the oxidation of pyrite.

In the processes connected with oxidation and enrichment the silver generally keeps close to the lead. Gold, so far as there is any evidence of its concentration in the lead-zinc ores, appears to accumulate in the zone of oxidation.

OXIDATION AND ENRICHMENT OF THE FARNCOMB HILL VEINS.

Immediately in advance of oxidation the veins of Farncomb Hill consisted of pyrite, chalcopyrite, sphalerite, galena, calcite, and gold in various proportions. Some wire gold has been found in the unoxidized vein material, but not far below the zone of general weathering, and the principal concentration of the native metal was unquestionably connected with oxidation. Two intimately related processes appear to have been effective in enriching these veins. These, in the order of their action at one place, were (1) enrichment by solutions depositing calcite, galena, gold, and perhaps sphalerite below the zone of oxidation and (2) enrichment in the zone of oxidation by solution and redeposition of the gold.

It is clear that during the weathering of these veins the gold was acted on by some very efficient solvent, for otherwise it would be impossible to account for the large crystalline masses of gold characteristic of the hill. These could not have been deposited in the veins as part of their original fillings, for they are limited to the oxidized zone, and the once very productive placers below the hill show that this zone can not coincide with originally rich upper portions of the veins. Evidently the original tops of the veins have been eroded away and their contained gold in part has been strewn along the ravines and down the main valleys, and in part has seeped down in solution along the fissures and been deposited in segregated masses. Active as solution must have been, erosion apparently was overtaking it; at least the richness of the placers proves that the gold was not carried down and redeposited fast enough to escape the forces of mechanical disintegration.

As is well known, gold is a chemically inert substance, and ordinarily in the weathering of veins remains behind in the gossan or undergoes a merely mechanical concentration in consequence of the tendency of the heavy particles to work down to the bottom of any loose material. In some veins, however, the metal goes into solution and local placers or auriferous gossan may be lacking. Various substances or combinations of substances are probably effective in dissolving gold in an oxidizing vein, and F. W. Clarke[1] gives a useful digest of experimental work

[1] The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, pp. 557-558.

along this line. The efficacy of a dilute mixture of sulphates, chlorides, and manganese dioxide as a solvent of gold was long ago demonstrated by Richard Pearce,[1] who pointed out the applicability of such a mode of solution to explain the concentration of gold at the base of some gossans. Pearce, it is of interest to note, used native gold from the Ontario mine in his experiment. Some years later T. A. Rickard [2] obtained similar results, and recently W. H. Emmons [3] has called renewed attention to the possible influence of manganese dioxide in promoting solution of gold during the oxidation of a deposit and has collected considerable evidence in favor of this view. A. D. Brokaw,[4] working on the problem from the experimental side, has confirmed the conclusion of H. N. Stokes [5] as to the insolubility of gold in ferric sulphate alone at ordinary temperature and the results obtained by Pearce and Rickard with manganese dioxide. Brokaw concludes that mixtures of ferric sulphate, sulphuric acid, and sodium chloride in the strengths found in mine waters will readily dissolve gold in the presence of manganese dioxide, that free hydrochloric acid is more effective than ferric chloride in a solvent mixture, and that the presence of ferrous salts does not seriously diminish the solvent power of the solutions, provided manganese dioxide is present. In other words, ferrous salts under these conditions are unstable and quickly become ferric salts.

Inasmuch as the veins of Farncomb Hill contain sphalerite and as a manganiferous carbonate occurs in the Wire Patch mine in the same hill, it was thought that possibly the remarkable concentration of gold in these veins might be due to the action of solutions containing sulphates and chlorides in the presence of manganese dioxide, but tests of partly oxidized dark sphalerite from the Silver vein showed only a minute quantity of manganese, and some oxidized material from the Reveille vein showed none. Nor is it likely that in this elevated and well-watered region chlorides were ever abundant in the waters along the veins. Accordingly, while it can not be said that the veins are altogether free from chlorides and manganese dioxide, it does not appear that these constituents were ever so abundant as would accord with the supposition of their being an essential factor in the concentration of the gold.

On the other hand, attempts to single out that essential factor have been unavailing. All or nearly all the veins contain a little copper, and there is a suggestion that the presence of the salts of this metal may have had something to do with the solution of the gold, especially as well-developed wire and flake gold was observed some years ago implanted on oxidized copper ore in quartzite in the Globe district, Arizona;[6] but cupric sulphate, according to Stokes, has no appreciable solvent power up to 200° C., and it is doubtful whether the carbonates would be any more effective.

Whatever may have caused the solution of the gold, the conditions for its deposition in rich pockets were almost ideal. Solutions traveling down the narrow fissures met others working slowly down the dip of the shales, particularly along bedding slips and along the surfaces of the sheets of porphyry. Thus waters carrying gold mingled at certain places with others depleted of the oxygen with which they started and possibly carrying more or less organic reducing matter picked up from the shale. The most important reducing and precipitating agents, however, were probably the sulphides already present in the veins and the pyrite finely disseminated through the wall rocks. There is a strong suggestion from the shape of some of the gold masses that their deposition began along the cleavage planes of calcite, opened probably by the corrosive action of descending acid waters. Still other masses appear to have formed, in part at least, below the direct effects of oxidation, their deposition being accompanied by that of calcite, galena, and sphalerite. The masses of gold show from their structure that each original particle of the metal became a nucleus upon which accumulated more of the gold drawn from the solutions by the attraction of the growing mass until finally, through the extension and coalescence of the smaller bodies, there resulted the branching crystal-coated forms for which the hill is famous.

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1 Address of retiring president: Proc. Colorado Sci. Soc., vol. 2, 1885–1887, p. 3. See also Trans. Am. Inst. Min. Eng., vol. 22, 1894, p. 739.
2 Trans. Am. Inst. Min. Eng., vol. 26, 1896, p. 978.
3 Outcrop of ore bodies: Min. and Sci. Press, Dec. 11, 1909, p. 782.
4 The solution of gold in the surface alterations of ore bodies: Jour. Geology, vol. 18, 1910, pp. 321–326.
5 Experiments on the solution, transportation, and deposition of copper, silver, and gold: Econ. Geology, vol. 1, 1906, p. 650.
6 Ransome, F. L., Geology of the Globe copper district, Arizona: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 154–155.

GENESIS.

To the investigator no phase of the geologic study of a group of ore deposits is more important or attractive than the problem of their origin, and there are few mining men so engrossed in the business of profitably adjusting tenor, tonnage, and treatment as to be without some interest in the same inquiry. The most absorbing questions, however, are generally those most difficult to answer satisfactorily and the reader who has followed the preceding descriptions scarcely need be told that the conditions at Breckenridge are not those likely to illumine with much additional light the dusky corners of ore genesis.

In a general way the principal ore-bearing fissures were probably initiated and perhaps controlled in direction by the great east-west stresses that accompanied the conspicuous post-"Laramie" disturbance of the Cordilleran region. This accords with the conclusion reached by Spurr and Garrey [1] for the near-by Georgetown quadrangle and there are no facts derivable from the Breckenridge district that suggest any other hypothesis. During this period of diastrophism, which, although geologically brief, nevertheless may have had considerable duration measured by ordinary time units, the monzonitic porphyries were intruded and this igneous activity appears to have been followed by the faulting along the west sides of the Tenmile and Front ranges that has separated the sediments of the Tenmile district from those of the Breckenridge district and has brought the Upper Cretaceous shale east of Breckenridge against the pre-Cambrian. So far as study of the Breckenridge area goes there is nothing to show that the porphyry was not intruded during or after the faulting. The assignment of priority to the intrusions rests entirely upon the work of Emmons [2] in the Leadville and Tenmile districts.

The ore-bearing fissures, as has been shown, are not important elements of the regional structure and were probably opened by minor or secondary stresses. In the study of the Breckenridge area the temptation to bring them into relation as subsidiary fractures with the great north-south dislocations represented by the Mosquito fault and by the Mount Guyot fault zone was strong. But Emmons has determined the Leadville and Tenmile ores to be older than the Mosquito fault, and the investigation of the small Breckenridge area has afforded no ground for questioning his conclusion. It is probable, however, that the movement along the Mosquito and Mount Guyot faults has been recurrent and consequently it is difficult to be sure that the faulting may not have begun before the deposition of ore and have continued after it perhaps up to the present time. With each slip along these principal lines of weakness there would probably be renewal of movement along the ore-filled fissures and at times the development of cross faults such as that which has offset the Siam and Iron mines. Some fissures, such as those of the Jessie mine, may have been formed by very slight movement, perhaps nothing more than a mere slipping or settling of the porphyry intersected by them upon the generally underlying shale.

However formed, the fissures were filled primarily with pyrite, sphalerite, and galena, the sulphides containing more or less gold and silver. Quartz was deposited also in the veins in the pre-Cambrian rocks but is almost entirely lacking from the deposits in the porphyries and sedimentary rocks.

That this deposition was connected in an essential way with the prophyry intrusions which it followed closely in time is beyond question. Emmons [3] some years ago pointed out the close association of porphyries and ore in central Colorado, and Spurr and Garrey,[4] in their work on the Georgetown quadrangle, have recently enlarged upon this significant relationship.

In spite of the generally feeble contact effects of the monzonitic intrusions in the Breckenridge district, the invading rock has in some places changed the adjacent sedimentary rock to an aggregate consisting mainly of garnet and epidote, and the sporadic occurrence in several parts of the district of masses of similarly altered rock, many of them associated with abundant sulphides and some of them with specularite, indicates that at one time the rocks were penetrated by hot solutions capable of producing some of the changes characteristic of contact meta-

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[1] Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 118.

[2] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886; Tenmile special folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[3] Tenmile special folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898, p. 6.

[4] Prof. Paper U S. Geol. Survey No. 63, 1908, p. 129-135.

morphism. There is no definite line to be drawn between the development of these metamorphic silicates and the deposition of sulphide ores, although where silicates and sulphides occur together the sulphides are, in part at least, slightly younger.

Whence came the various ore constituents? Consideration of this question may be introduced by an attempt to gain as clear a picture as possible of the ore-bearing fissures as channels for moving solutions.

It has been shown in the preceding pages that individually the veins are not traceable for very great lengths and that some of them obviously die out along the strike. Some years ago, in the discussion of a region where fissure veins are remarkably numerous and well exposed,[1] I called attention to the probability that the vertical range of a fissure is not necessarily so great as to be practically infinite but that, before truncation by erosion, the length and depth of the fissure were roughly equal, or at least bore some simple proportion to each other. That some fissures die out at the depths reached in mining in other districts, more thoroughly developed than Breckenridge, is a well-established fact and there appears to be little ground for supposing that the comparatively short, deeply eroded fissures at Breckenridge, opened originally with no great displacement, continue downward with undiminished width for many thousands of feet. Such an idea is obviously untenable with regard to fissures like those in the porphyry of the Jessie mine or those associated with some of the pockety occurrence of gold in quartzite. The Farncomb Hill veins also can scarcely be thought of as retaining their identity for many hundred feet below the level of the Fair tunnel. Much more reasonable, especially in view of the different kinds of country rock that in this district would have to be traversed by most veins having great vertical ranges, is the supposition that the vein fissures have never extended down as direct, open, and continuous channels to a vaguely imaginable magmatic source but that they pinch or split into small branches at moderate depth and finally lose themselves in the minute irregular fractures from which no rock in a disturbed region is wholly free. In other words, for the conception of a single, simple profound cleft up which solutions from magmatic or other abyssal sources could freely and rapidly ascend is substituted a different picture, that of fissures extending only to depths of a few hundred or a few thousand feet, there dying out and linked perhaps by small fractures with other fissures, which also in turn die out, the general tendency of the complex system being toward smaller and less numerous fissures with increase of depth and the whole being complicated by more or less later faulting. According to this view, few if any veins in the Breckenridge district were filled by the direct ascent of solutions from below. The fissures now occupied by the veins were, it is believed, semi-isolated spaces, partly filled with crushed or shattered rock into which the ore-depositing solutions with their contained gases penetrated at many points after pursuing devious courses through other fissures and through rock rendered porous by minute fractures, such as those described on page 56, or possessed of this property by virtue of original texture. If this view is substantially correct it follows that the solutions, whatever may have been their origin, deposited their load only after they had exceptional opportunity to search the solid rocks through which they passed and to extract from these rocks such constituents as they could dissolve. The next questions are, What were these solutions to start with and what did they gather on their journey?

It is clear that the ore-bearing solutions carried large quantities of sulphur, sufficient not only to fill the veins with sulphides, but to impregnate the country rock extensively with pyrite and less abundantly with sphalerite and galena. Of all the constituents, this sulphur, probably in the form of hydrogen sulphide, can be most confidently assigned to magmatic sources. It has been shown also, in Chapter VII (pp. 93–102), that the solutions were rich in carbon dioxide, or bicarbonates, and it is highly probable that carbon dioxide with hydrogen sulphide and water issued from the deep-seated cooling masses of monzonitic magma from which the visible porphyry sheets are presumably offshoots. The sheets and small intrusions as they solidified must themselves also have contributed a share of these constituents. While most of the carbon dioxide is supposed to have been of igneous origin, it is to be remembered that, as A. Béchamp[2]

[1] Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, p. 62.
[2] Recherches sur l'état du soufre dans les eaux minérales sulfurées: Annales chim. phys., 4th ser., vol. 16, 1869, p. 202.

long ago showed, hydrogen sulphide in solution will dissolve limestone, producing the soluble calcium hydrosulphide ($Ca(SH)_2$) and calcium bicarbonate ($H_2Ca(CO_3)_2$). Thus a hydrogen sulphide water in passing through rocks containing alkali-earth carbonates becomes carbonated.

The wall-rock alteration discussed in Chapter VII (pp. 93–102) indicates that the solutions when they reached the place of ore deposition, especially in the monzonite porphyry, contained in abundance the bicarbonates of iron, magnesium, manganese, and calcium; for the brown or sideritic carbonate developed in the porphyry, as contrasted with that filling cracks in the ore, appears to be connected with the original deposition rather than with any reworking of the vein materials by descending surface waters, although it must be admitted that deeper mining would probably afford much more satisfactory evidence on this point. The source of the constituents of the sideritic carbonate is not known with certainty, but they are believed to have been leached from the solid rocks by the hot carbonated solutions on their roundabout journey to the fissures in which the ores were deposited. Recently F. Henrich[1] has studied experimentally the action of carbon dioxide in aqueous solution on finely pulverized rocks. He found that even at ordinary temperatures and atmospheric pressure a notable proportion of the rock went into solution, the loss in a basalt being nearly 3 per cent. According to Henrich, no constituent of the rocks wholly escapes attack, but those most readily extracted are manganese, calcium, and iron. In rocks where it occurs in important quantity magnesium also is readily removed. In view of these results it appears very unlikely that thermal carbonated solutions, necessarily under considerable pressure, could soak their way through many small openings in the rocks without robbing these of precisely the constituents that were subsequently introduced into the wall rocks of the veins. Such solutions would extract most from the femic and calcic rocks, and this in part explains the pronounced carbonatization associated with the deposition of ores in and near the monzonite porphyry and the very slight development of carbonates in the siliceous quartz monzonite porphyry or in the pre-Cambrian rocks. Presumably the original characters of the altered rocks have also much to do, in a receptive way, with the differences in wall-rock alteration, the introduction of carbonates being more easily brought about in those rocks, already rich in primary calcic and femic minerals, that yield on decomposition the bases to combine with carbonic acid as comparatively insoluble compounds, whereas in siliceous potash-bearing rocks the effect of the carbon dioxide is most manifest in the development of sericite and the removal of the alkali earth bases. Although the ore-bearing solutions are thought to have obtained their carbonate bases from the rocks, it is not supposed that they were derived from the immediate wall rock of the present veins. If so, there might be expected to intervene between the monzonite porphyry to which carbonates have been added and the nearly fresh rock a few feet away from the veins a variety from which iron, magnesium, calcium, and manganese have been removed. No such change has been noted. On the other hand, the rock showing an addition of ferruginous carbonate appears to pass gradually into nearly fresh rock, in which, however, as described on page 56, there are microscopic fractures filled with carbonates. It is probable that in part through such minute channels the bases of carbonates were gathered at various distances from the veins, the loss of these constituents in a rock at any one place being probably too small to greatly change its appearance or character.

The Breckenridge district presents no decisive evidence as to the source of the metals combined with sulphur in the veins. Much of the pyrite in the wall rocks was formed by the action of hydrogen sulphide on the iron originally combined as silicates or magnetite; but the pyrite in the veins with the accompanying sphalerite and galena has been brought from some distance. There is nothing in the occurrence of these sulphides that denies them an origin as magnetic emanations. On the other hand, the way is equally open for anyone to regard them as having been leached by thermal and gas-charged waters from the solid rocks. The latter speculation has in its favor, first, the consideration that thermal waters could hardly have made their way through the rocks by the circuitous routes supposed without gathering considerable material on the way, and, second, the association of certain kinds of deposits with

[1] Über die Einwirkung von kohlensäurehaltigen Wasser auf Gesteine und über den Ursprung und dem Mechanismus der Kohlensäureführenden Thermen: Zeitschr. prakt. Geologie, vol. 18, 1910, pp. 85–94.

particular kinds of country rock, thus suggesting that the adjacent rock in each case had something to do with determining the contents of the deposit. Yet it can scarcely be supposed that the metallic constituents of an ore deposit like that of the Jessie were derived entirely from the comparatively small body of porphyry within which they lie. On the whole, it appears that the local evidence available is insufficient for an opinion of any real value. It is quite possible that each of the metals may in part have been given off from cooling magma and in part collected from the solid rocks. In their study of the Georgetown and Idaho Springs areas Spurr and Garrey [1] concluded that whereas the earthy gangue minerals and the iron and manganese of the veins were derived from the country rock, the more valuable metals—gold, silver, copper, lead, zinc, arsenic, and antimony—were given off from solidifying magma. They based their conclusion mainly on the circumstance that they were able to distinguish two groups of deposits, each being related to a different set of intrusive rocks, the argument being that if the metals were all derived from the solid rocks by leaching the ore deposition would have been of the same character after each period of eruptive activity. This, however, is perhaps not entirely conclusive, for the difference may have inhered in the solvents given off from the two magmas, enabling each to make a different selection of metals in its journey through the rocks. Moreover, rocks subjected to one leaching might not yield constituents in the same proportion on a second leaching. As these authors remark:

> If the evidence afforded by either of these vein groups was taken separately, the hypothesis that these rarer metals [gold, silver, etc.] have been derived from the hot ascending magmatic waters from the rocks through which these waters ascended is as fully justified as that which supposes the metals to have been given off from the magma along with the mineralizing agents, since the crystalline igneous rocks through which the waters passed contain some, if not all, of these metals in small quantities.

In the Breckenridge district there is no representation of the second or alkali-rich magma which in the Idaho Springs district followed the monzonitic magma and no evidence of two distinct periods of ore deposition. At the present time the district contains no thermal springs.

AGE OF THE DEPOSITS.

As the deposition of the Breckenridge ores, part of which are in Upper Cretaceous shale, followed the post-"Laramie" diastrophism, they are unquestionably of Tertiary age. They were deeply eroded before the glacial epoch and probably were deposited in the early part of the Tertiary. During later Tertiary time erosion and enrichment were at work and a layer of rock of unknown thickness was removed. The surface was probably reduced several thousand feet before the beginning of the Pleistocene.

[1] Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 157.

CHAPTER XIV.

GOLD PLACERS.

CLASSIFICATION.

The placers of Breckenridge may be divided into three general classes—(1) the bench or high-level placers, (2) the deep or low-level placers, and (3) the gulch washings. The bench placers are those in the deposits described in Chapter VI (pp. 72–76) as terrace gravels and older hillside wash. They have been worked almost entirely by hydraulic methods. The deep placers are those in what have been described as the low-level gravels. They were formerly worked in part by bedrock drifting and unsuccessfully by hydraulic elevators but are now dredged. The gulch washings include placers of small area and generally of steep slope lying in the bottoms of minor gulches. Their material as a rule is soil and angular rock waste from the adjacent slopes. These were the first placers to be profitably worked in this district, the methods employed ranging from panning and rocking to booming and the use of high-pressure water jets from giants or monitors. These three groups of placers will be described in the general historical order of their exploitation as sketched in Chapter I (pp. 16–20).

GULCH WASHINGS.

The most noted gulch washings in the district are those of Georgia, American, and Dry gulches, on the north slope of Farncomb Hill. These were first worked in the early sixties, and their total yield has been variously estimated at $5,000,000 to $10,000,000. The material of these placers is unconsolidated soil and shale detritus, with scattered angular blocks of porphyry, and attains a maximum thickness in the bottoms of the gulches of about 25 feet. The bedrock is generally shale, but this is cut by some dikes of porphyry, and porphyry is the general bedrock along the northwest side of the placer workings of upper Georgia Gulch. The shales strike generally across the gulches and dip downstream, thus forming ideal natural riffles for catching the gold. Moreover, they weather into small fragments such as are easily washed through the sluices and constitute a bedrock whose comparatively soft superficial layer, containing more or less detrital gold, was easily removed by the miners.

Work on these placers has long ceased, and little can now be learned of the methods used in exploiting them, of their tenor per yard, or of the occurrence and character of the gold. Presumably pans and rockers were first employed, and there appears to have been some drifting practiced at the lower end of the gulch. Hydraulic washing was later introduced, and long after the rich alluvial material had been exhausted the dumps of some of the Farncomb Hill tunnels, with much detritus from the hillside, were washed down over the old placer ground. According to all accounts much of the gold was coarse, and most of the nuggets showed the wiry and flaky texture afterwards found to be so eminently characteristic of the gold from the Farncomb Hill veins. There is no doubt as to the origin of the placer gold of these gulches. It came from the wonderful little veins in the shale of Farncomb Hill and perhaps partly also from similar veins, of which the rich parts have been eroded away, in the shale of Humbug and Brewery hills. It had not been subjected to the pounding and wear of distant transport along a bowldery stream bed, but had crept gently down the slope with accompanying soil and rock fragments for a few hundred feet to the bottoms of the little ravines, where it gradually accumulated in a rich narrow layer or ribbon close to bedrock.

Another deposit of note that probably belongs with this class is the Wire Patch placer, on the southwest slope of Farncomb Hill, a mile east of Lincoln. There is scarcely any well-defined gulch here, and the deposit is little more than a patch of shaly soil carrying many porphyry fragments that has accumulated on shale bedrock near the base of the steep slope on which the Elephant ore body comes to the surface. The gold evidently came largely from the Elephant ore body and perhaps in part also from the veins of the Ontario mine. It is long since work was done in this placer, which is nearly exhausted, although there is said to be a little auriferous detritus of good grade at the head of the placer, under the Wire Patch mill.

Some washing was done in Australia Gulch, which opens on the south side of French Gulch about a mile west of Lincoln, but this was not nearly so productive a ravine as Nigger Gulch, farther west, where, on the Lillian Vale or T. H. Fuller placer, the material washed was soil and angular fragments of porphyry on a porphyry bedrock. The gold appears to have been derived from the disintegration of the Dunkin, Juniata, and Washington groups of veins on Nigger Hill.

Gibson Gulch, on the south side of Gibson Hill, contained a small but rich placer deposit with shale and diorite porphyry bedrock. There was at one time a little settlement in the gulch, and the gold is said to have been obtained with pans and rockers.

The bottoms of Illinois Gulch and its branches are probably best classed as gulch placers and were long ago worked over by primitive hand methods. North of the gulch and east of the main tunnels of the Washington mine a large pit, shown by the contours on Plate I (in pocket), has been excavated by hydraulic mining in the Dakota quartzite. The rock in this vicinity is much fractured, probably in consequence of proximity to the fault shown in Plate I. The material washed consisted of angular blocks of quartzite, some of large size, mingled with earth, the whole resting with no sharp distinction upon a very rough bedrock of fractured quartzite. I was unable to learn how successful the operators of this placer were or when the work was done. The gold obtained had not traveled far and was probably deposited originally in the fissures of the quartzite.

In the class of gulch placers, also, are included some shallow washings along the Blue southwest of Little Mountain. Real bedrock does not appear to have been reached in these pits and the material worked over by the early miners probably consisted for the most part of auriferous and argentiferous detritus that had slid or crept down from Little Mountain over the moraine.

Many other examples of gulch placers might be cited and described, but their characters are so similar and all have so long been exhausted that further detail is scarcely necessary. Virtually every gulch leading down from known auriferous lode deposits has yielded its quota to the total placer output. It can not be said, however, that the former productivity of the placers is directly proportional to the known importance of the respective lodes. Thus on the south side of the Swan the placers of Galena Gulch, in which no important mine has yet been opened, have been more productive than those of Summit Gulch, in which is the Hamilton mine, or than those of Browns Gulch, in which is the Cashier mine. Probably in this, as in other placer districts, much gold may have been contributed to the placers from veins too small or too uneven in tenor to stope or may have been supplied by the disintegration of rich shoots in veins of which only low-grade remnants have been left.

The slope of the bedrock in the gulch placers is generally much steeper than the gradients of large streams and some of the richest placer ground on Farncomb Hill lay on a slope of 1 in 5. Retention of large quantities of gold on such a grade was probably favored by the angular form of the nuggets, by the laminated character of the bedrock, and by a more abundant supply of soil and rock detritus than could be scoured out by the small streamlets in the gulches. In these deposits soil creep may have contributed fully as much as flowing water to the concentration of the gold.

BENCH PLACERS.

The general distribution and character of the terrace gravels and older hillside wash have been described in Chapter VI (pp. 72–76). They have been extensively worked in the past by the ordinary hydraulic method, but large quantities of material, as may be seen from Plate I (in pocket), are as yet untouched, the bulk of gravel washed being probably less than 5 per cent of the total volume of the deposits. The bench placers were actively worked up to about 10 years ago, but since that time this form of mining has declined and in 1909 no hydraulic work was in progress. The causes of the decline are chiefly the working out of the richest known areas up to the ditches that supplied the water for the giants. Although in some placers there is good gravel above the ditch the quantity is probably not sufficient to encourage anyone to construct a new high-level ditch many miles in length or to purchase water rights for the purpose. In other placers the increasing thickness of the gravels as they are followed in from the first exposure on the hillside and the greater cost of handling the waste have turned the scale against a deposit that probably was nowhere of high grade. In one or two cases the hydraulic miner has been enjoined by owners of low-level placers from washing débris over their property.

It is noteworthy that although several placer pits have been opened in the terrace gravels along the Blue these placers have never been worked as extensively or as successfully as those on Gold Run and French Gulch near their mouths.

The Peabody and near-by placers in the older wash of Gold Run (Pl. XVI, p. 74) were probably more persistently worked and more productive than any other group of bench placers in the district, their total output being generally estimated at about $750,000. The character of the material, angular detritus loosely held in a friable matrix, has been described on page 75 and is illustrated in Plate XVI, *B*. The maximum depth of the deposit is about 40 feet. The bedrock is generally black shale, from which it was a comparatively easy matter to collect virtually all of the gold.

The gold of the Gold Run placers was certainly not brought from a distance, but probably worked slowly down the slope, chiefly from a series of veins exploited in the Jumbo, Extension, and Little Corporal mines. The process of concentration was thus similar to that operative in the formation of the gulch placers.

Another important group of workings is that generally known as the Sisler or Mekka placers, on the French Gulch slope of Nigger Hill, of which a general view is shown in Plate IV, *B* (p. 18). The material here differs from that in Gold Run in being terrace gravel, which contains well-rounded bowlders, many of them decomposed, rudely interstratified with yellow sandy clay. These gravels range from 10 to 20 feet in thickness, are readily broken down by water under pressure, and rest generally on decomposed quartz monzonite porphyry. The large bowlders, up to 3 feet in diameter, are as a rule in the lower part of the deposit, the upper part being more clayey and more distinctly stratified.

Very little information regarding the Mekka placers is now obtainable in the district. The roundness of the bowlders with which the gold is associated, however, suggests that in part at least it was brought down by a powerful stream from points farther up French Gulch.

The last place at which hydraulic washing was practiced in the district was at the Banner placer (Pl. XIV, *B*), on the west side of the Blue about a mile north of Breckenridge. The character of these gravels has been described on page 73 and is illustrated in Plate XV (p. 72).

DEEP PLACERS.

GENERAL FEATURES OF THE CHANNELS.

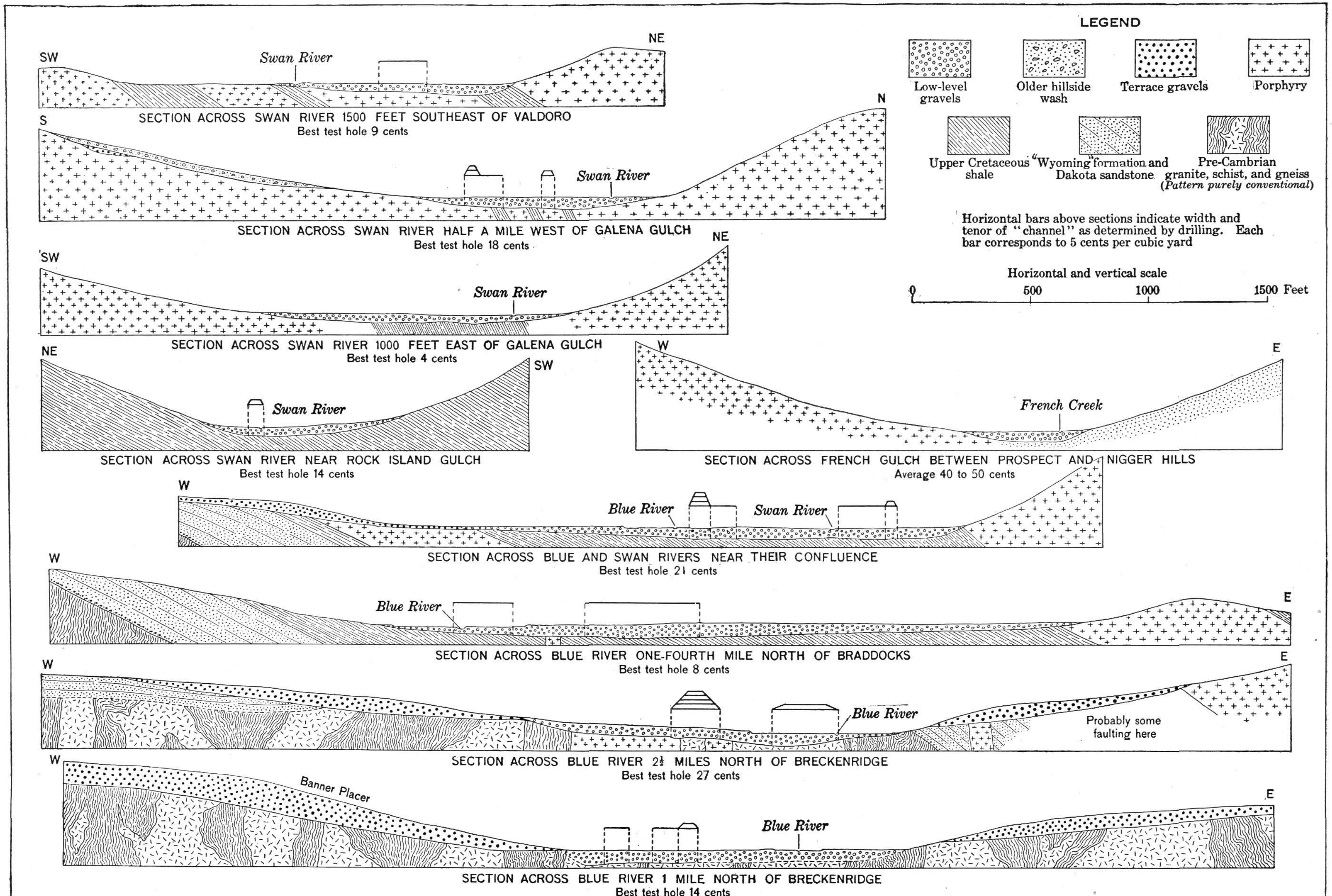
The low-level gravels, as already noted in Chapter V (pp. 78–79), occupy the bottoms of the present valleys of the larger streams and attain economic importance along Blue and Swan rivers and in French Gulch. Their distribution has been described in the chapter referred to and is shown on Plate I (in pocket). The thickness of the gravel along the Swan and in French Gulch rarely exceeds 50 feet. Along the Blue the maximum depth of the bedrock channel ranges from 50 feet in the vicinity of Valdoro to about 90 feet near Breckenridge. Consequently, unless there has been some recent tilting of the region, the old stream, along this part of its course, flowed on a lower gradient than the present Blue River, which has a fall of about 100 feet to the mile between Breckenridge and Valdoro. About 2½ miles north of Breckenridge the greatest depth to bedrock, as shown by drilling, is 54 feet and near Braddocks it is 60 feet, the line of greatest depth lying east of the present river in this part of its course.

The width of the gravel-filled valley bottoms ranges from 600 to 3,000 feet along the Blue, from 500 to 1,200 feet along the Swan, and from 700 to 1,500 feet in French Gulch. It thus appears that the gravel occupies comparatively broad-bottomed straths whose slopes merge without abrupt change of grade into those of the bounding hills. The general shape of these valleys in cross section is shown in Plate XXXII. Evidently the streams before the deposition of gravel began were well graded; they were no longer actively engaged in deepening their channels but were leisurely widening and smoothing them as if in preparation for future dredging operations. Drilling and dredging show that the rock bottoms of the channels are, on the whole, smooth, although at a few places where the streams have cut through quartzite that rock appears to be sufficiently rough, in connection with its hardness, to tax severely the machinery of dredges attempting to scoop up the auriferous surface layer of the bedrock. Shale as a rule is so soft as to be easily excavated by the buckets, and the porphyries, owing to more or less decomposition, also constitute a tractable bottom material.

By no means all of the gravel is commercially auriferous. The workable strip, or "channel," in the dredgers' parlance, is generally from 180 to 400 feet wide and follows a sinuous course along the valley. It has no regular relation to the channel of the present stream nor does it invariably correspond to the deepest part of the bedrock trough. Its lateral limits are indefinite and irregular. Both they and the tenor of the deposit are in many places clearly affected by the proximity of the lateral gulches, which themselves yielded alluvial gold to the early placer miners. Thus the gravels of French Gulch are especially rich below Nigger Gulch and some of the best ground known on the Swan is at the mouth of Galena Gulch. Some rich gravel occurs also on the Swan for some distance below the mouths of Georgia and American gulches, in which were the most productive shallow placers worked in the district.

MATERIAL.

The gravels are generally loose and facilitate dredging by the readiness with which they crumble when they are undercut by the buckets. They show some differences in this respect, however, those on the lower Swan caving more easily than those on French Creek. The chief obstacles to profitable exploitation are the coarseness and depth of the material. The ground least amenable to dredging is that along the Blue, where the gravel is not only thicker than on the other streams, but contains a greater proportion of large bowlders. In the Gold Pan workings, close to the terminal moraine near Breckenridge, bowlders 6 feet across are by no means rare, those 3 feet 6 inches across are common, and those 18 inches to 2 feet are abundant. These are mostly of pre-Cambrian material, but many are of porphyry. All are more or less water worn and most are well rounded. A general view of these gravels as exposed in the walls of the Gold Pan pit and an illustration of some of the bowlders taken from the same excavation may be seen in Plate XVIII (p. 78). These large masses, weighing 4 or 5 tons, had to be swung out of the pit with derricks and the expense of handling them contributed largely to the failure of the Gold Pan hydraulic elevators. The material is ill assorted, is not perceptibly stratified, and contains the large bowlders distributed from top to bottom. Lower down the river the size of the bowlders decreases, but those 4 feet in diameter are raised by the dredge near the mouth of the Swan and bowlders over 3 feet across are embarrassingly abundant. The gravels of the Swan below Swan City are not so coarse as those on the Blue and offer no difficulties to well-constructed modern dredges. On the upper Swan, near Georgia Gulch, the material is coarser than on the lower reaches of the stream. In that part of French Gulch where dredging is in progress, between Prospect and Nigger hills, the bowlders range from 3 feet in diameter down, 18-inch and 2-foot ones being abundant. They consist mostly of porphyry and quartzite and are not so well rounded as those of the Blue, which have in great part been derived from the older bench gravels.



SECTIONS OF AURIFEROUS CHANNELS IN THE BRECKENRIDGE DISTRICT.

See page 177.

TENOR.

The Breckenridge deep gravels, in comparison with some placers in the Lena Basin of Siberia, which, according to C. W. Purington,[1] average as much as $10 a cubic yard, are of decidedly low grade. Their tenor, owing to some local tendency toward exaggeration and to the usual reluctance on the part of those engaged in dredging or prospecting to publish the financial results of their operations, is not a matter of common knowledge. The statement is frequently made, for example, that the gravels of the lower Swan and of the Blue near Valdoro average about 20 cents and that the gravels of French Creek average from 50 cents to $1 a yard. Much higher figures are often given and it is not unusual to hear that most of the Swan gravel averages 50 cents or that certain areas of prospected but unworked ground will yield an average of $1.50 a yard. In the prospectus issued a few years ago by the Gold Pan Mining Co. the average tenor of the Blue River gravels just south of Breckenridge was stated to be about 60 cents, which is clearly far above the mark.

Undoubtedly some rich spots are occasionally found where the gravel does carry over a dollar a yard, but extensive bodies of material averaging as much as 50 cents a cubic yard are certainly very rare. In French Creek one dredge working in unusually good ground below the mouth of Nigger Gulch excavated in 1909 an area of 10 acres on the Mekka placer and the gravel averaged 42 cents a yard. The other dredge in the same gulch is credibly reported to have worked some gravel carrying from 60 to 70 cents a yard, but the average is undoubtedly under 50 cents. A few years ago W. W. Dyar, who in 1902–1904 was general manager of the American Gold Dredging Co., bored a line of drill holes across French Gulch near its mouth and obtained an average of 25 cents a yard from a pay channel 200 to 300 feet wide and averaging about 30 feet deep.

The gravels on the Blue are undoubtedly of lower grade on the whole than those worked on French Creek. The ground already dredged on this stream near the mouth of the Swan is known to have had an average tenor considerably under 20 cents. Between a point about 2½ miles north of Valdoro and French Gulch the channel has been tested by 11 transverse lines of drill holes whose records were obtained in connection with this report.[2] The highest rate per yard indicated by any hole (calculated from outside diameter of the shoe) was 61 cents, just north of the confluence of the Blue and the Swan. A mile farther north the highest tenor found was 42 cents. Upstream from the mouth of the Swan the highest rate calculated in the series of holes here considered was 27 cents, just north of the highway bridge, 2 miles down stream from Breckenridge. The average of the best hole in each of the 11 lines is 23 cents and this is probably not far from the average tenor of the richest line along the old channel. This average would be materially reduced by taking into consideration those holes on both sides of this line that would be included in the workable width of the channel. Out of the 237 holes here discussed, there are 47 that give returns of 5 cents or over. The average of these is a little over 12 cents.

On the Swan the data from 15 sets of drill holes have been examined. The highest assays recorded are $1.49 a cubic yard just above the mouth of Summit Gulch and $1.19 a yard on the middle fork near Snyder's camp (bench mark 9823). The average of the best hole from each group is a little over 30 cents. Out of 96 holes, 46 afford returns of 5 cents or over and the average of these 46 is about 17 cents. If the two exceptionally rich holes mentioned above are omitted the average becomes a little less than 12 cents.

Such averages as those just given obviously do not represent the actual average gold contents of the gravels. The results of drill tests are more or less uncertain at best and differ materially with differences in the methods of calculation used to transform the assay returns from the drill sand into terms of value per cubic yard. The positions of the holes also should be taken into account and their records properly weighted in order to obtain from them a fair average of the whole. But notwithstanding these elements of inaccuracy the figures as given serve to indicate in a fairly definite way the general tenor of the deposits. It is scarcely necessary to note that all statements as to value per yard take into account the whole thickness of gravel

[1] Min. Mag., vol. 2, 1910, p. 298.

[2] There are also other holes whose logs are not available.

from surface to bedrock. Of course if barren overburden were eliminated very much higher returns than those given would be obtained in many places.

As a rule the gold is not evenly distributed through the gravel from top to bottom, but is concentrated in the lower 6 feet or in the decomposed surface layer of the bedrock. There are a few exceptional places where nearly the whole thickness of the gravel is auriferous. One of these is at the junction of the Swan and the Blue. A similar distribution of the gold is said to characterize some of the gravel near Dillon, north of the area here particularly studied.

DRILLING.

It was not until about 1902 that churn drills began to be used for prospecting the gravels. Exploration prior to that time was by the troublesome and expensive method of sinking shafts to bedrock through the loose and saturated gravel. During the last 15 years the Blue north of French Gulch and the Swan from its mouth to Georgia Gulch have been systematically prospected by transverse lines of drill holes, the holes on each line being generally 100 feet apart. Some of the older holes, however, are not in lines, but were bored at isolated places or in random groups.

Some drilling has been done also in French Gulch, especially on the Mekka placer of the French Gulch Dredging Co., but until the year 1909 very little systematic drilling was done on French Creek and there are few lines of holes that extend entirely across the valley.

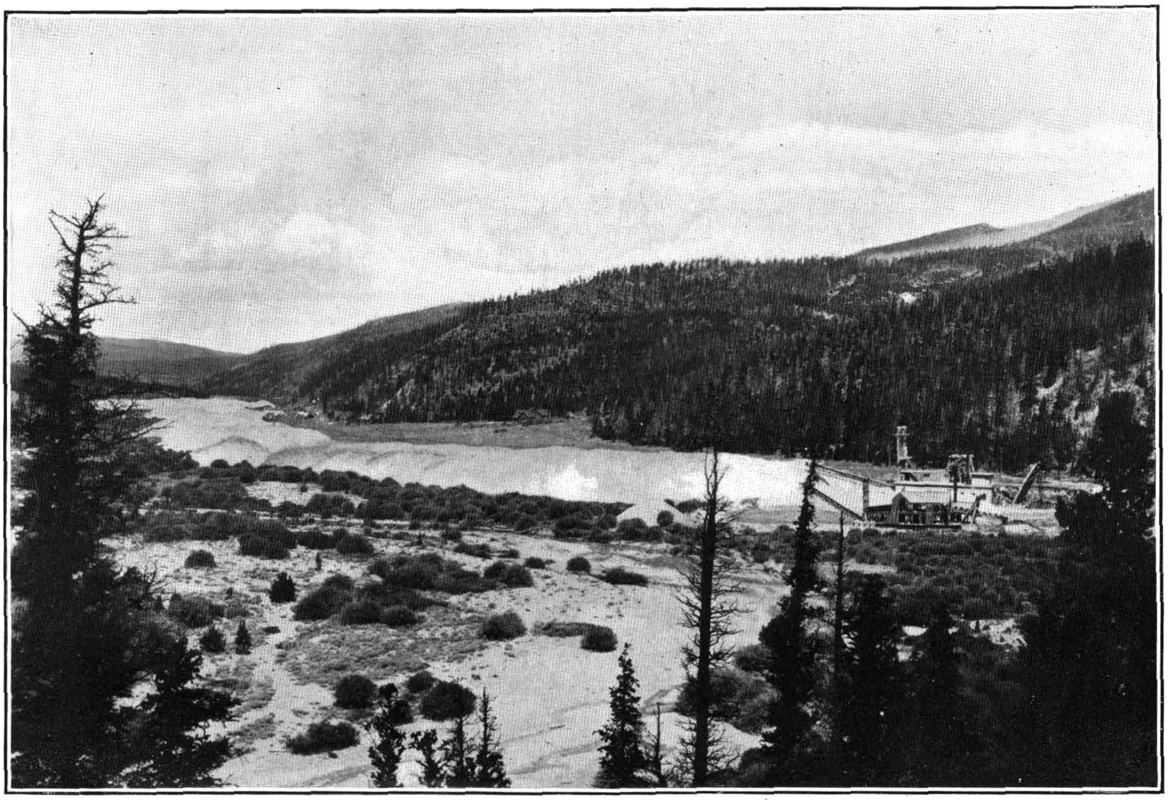
In the vicinity of Breckenridge the Gold Pan Mining Co. put down 30 or more drill holes on the Maggie placer, some of them north of the terminal moraine and some of them along the river where it has cut through the glacial material. The same company also did some drilling farther up the Blue, in the vicinity of the Goose Pasture. The results of these tests, however, could not be ascertained in 1909.

Ordinary portable Keystone drilling machines are used in prospecting. The methods employed are not altogether uniform. Some drillers advance the bit about a foot ahead of the casing, which is then driven down. Others drive the casing ahead of the bit wherever possible. By some samplers the sand is all put through a small rocker, the concentrates only being panned. By others all the material is panned. In 1909 one piece of ground was being appraised by panning the drill sands, counting the colors in the pan, and estimating therefrom the value of the gravel per yard. The Colorado Gold Dredging Co., on the other hand, accepts no such guesswork. The concentrates from the pans are treated with nitric acid and the gold is then amalgamated, ignited, and weighed.

The accuracy of drill prospecting evidently depends largely on the closeness with which the volume of the drill hole can be calculated—that is, the exact original volume of the column of gravel yielding a certain number of milligrams or centigrams of gold must be known in order to calculate from those data the number of cents per cubic yard of gravel. Two methods are ordinarily used. One consists in actually measuring the volume of the sand pumped from the hole. The other consists in calculating the volume of the hole on the supposition that it corresponds to the outside diameter of the shoe on the end of the casing, usually 7½ inches. In the records of the Colorado Gold Dredging Co. the results by both methods are given and are often at variance. As a rule, the results by the method of measured excavation are higher, especially in the older records. One of the earlier holes, for example, gave 4.6 cents a yard when the outside diameter of the shoe was used and 25.4 cents by the other method. According to Mr. W. H. Lohman, manager for the company, the method in which the diameter of the shoe is used is the more reliable and agrees more closely than the other with the results later obtained by dredging. In this report all statements regarding the tenor of gravels as determined by drilling are based on the method of calculation wherein the outside diameter of the shoe is used.

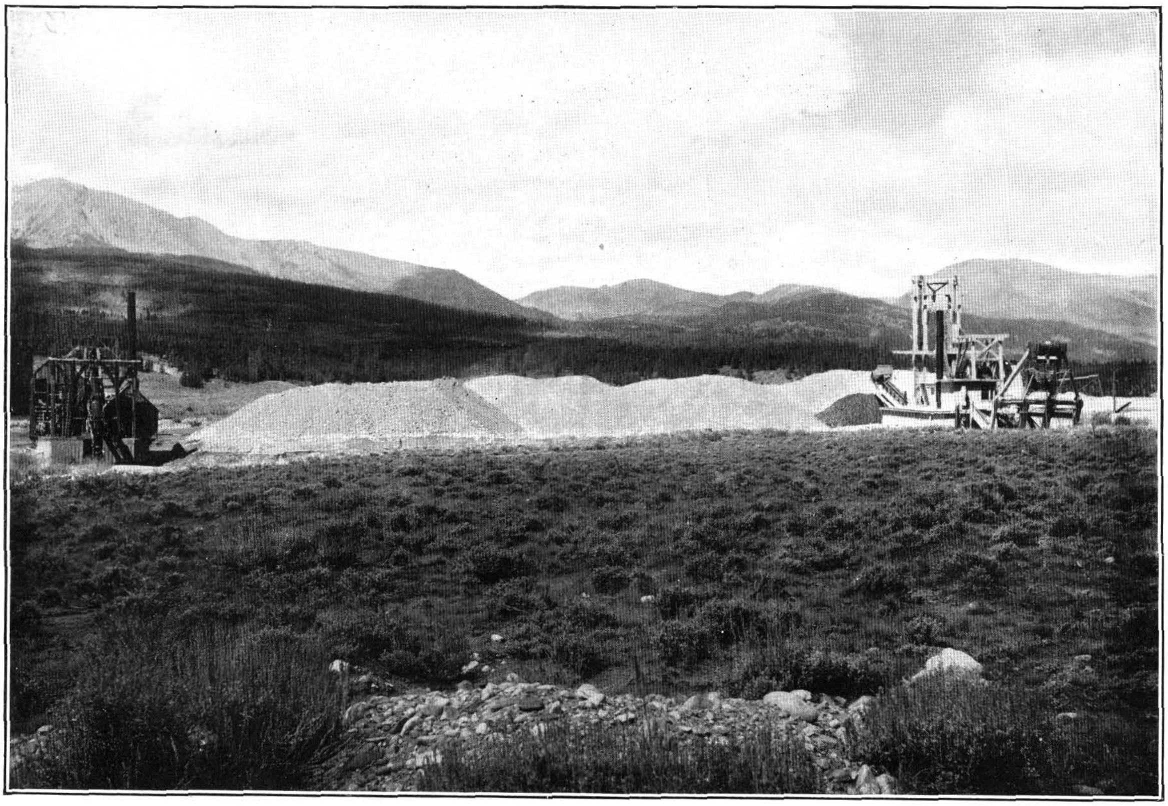
DREDGING.

The history of the development of dredging in this district has been given on pages 19–20. In 1909 there were four boats in successful operation. Near Valdoro the Colorado Gold Dredging Co. has two Bucyrus dredges of identical size and capacity. One, shown in Plate XXXIII,



A. GOLD DREDGE WORKING UP THE SWAN FROM VALDORO.

The view is north, down the Swan. The long ridge of gravel is the work of this dredge as far as Valdoro, the group of buildings in the distance. Below Valdoro the material was stacked by another dredge, which worked down to the Blue. The small, dilapidated machine in front of the larger craft is an old steam dredge that never moved far from the spot where it was launched.



B. ANOTHER VIEW SHOWING THE MODERN ELECTRIC DREDGE WORKING PAST THE OLD STRANDED STEAM DREDGE.

The view is northwest, partly down the Swan. The Gore Mountains appear in the distance to the right and the Tenmile Range is to the left.

is advancing up the Swan and the other (Pl. XXIV, *A*, p. 106), after working down the Swan from Valdoro, is moving up the Blue. These are electrically driven, the open-connected lines of forty-two 9½-foot buckets being actuated by 200-horsepower motors. The total horsepower of each dredge is about 450. The dredge on the Blue is designed to dig about 50 feet below water and the one on the Swan 40 feet. Both stack from 40 to 50 feet. The daily capacity varies from 3,000 to 4,000 cubic yards, depending on the character of the ground.

In French Gulch are the dredges of the Reliance Gold Dredging Co. and the French Gulch Dredging Co. The Reliance dredge is a double-lift machine of special design and is electrically driven, with a total horsepower of about 425. This dredge, originally driven by steam, has undergone many alterations and in 1909 its open-connected line of forty-two 9-foot buckets was replaced by close-connected 5-foot buckets. The actual capacity of this machine in August, 1909, was at the rate of about 2,800 cubic yards in 24 hours. The material from the buckets, after the removal of the bowlders by grizzly and trommel, falls to the bottom of the boat and is lifted by a centrifugal pump, requiring 100 horsepower for its operation, before passing over the sluices. It is claimed that this second lift scours the gold and renders it more amenable to amalgamation and that very large nuggets are occasionally caught on the Reliance dredge that would go out over the stacker on the other boats.

The dredge of the French Gulch Dredging Co., locally known as the Reiling dredge, is an electric dredge of the Bucyrus type with a capacity of about 2,000 yards a day.

The dredges of the Colorado Gold Dredging Co. and the Reiling dredge are supplied with power by the Central Colorado Power Co., which generates electricity at Shoshone, on Eagle River, about 8 miles from Glenwood Springs. The power for the Reliance dredge is furnished by Spruce Creek, south of Breckenridge. The water is delivered at the powerhouse on the Blue under a head of 500 feet, and drives dynamos that develop from 500 to 600 horsepower.

The cost of dredging probably varies considerably, being least on the Swan, where breakages and wear from large bowlders and hard bedrock are less than on the Blue or in French Gulch. According to Bradford and Curtis,[1] whose excellent article should be consulted by the reader who desires further details regarding the equipment of the Breckenridge dredges, the Colorado Gold Dredging Co. in 1908 dredged at an average cost of 8 cents a yard. Certainly the cost with a well-constructed dredge on French Gulch ought not to exceed this. On the other hand, the figure is probably high for the lower Swan, where the cost is reliably stated to be from 4 to 5 cents a yard.

It is entirely practicable, as Mr. B. S. Revett has shown with the Reliance dredge, to operate through the winter, but it is an open question whether this is profitable. The Reliance dredge ran through the winter of 1908–9 but lost valuable months in the summer in overhauling and alterations.

[1] Bradford, A. H., and Curtis, R. P., Dredging at Breckenridge, Colo.: Min. and Sci. Press, Sept. 11, 1909, p. 366.

CHAPTER XV.

THE GEOLOGIC PAST AND THE ECONOMIC FUTURE OF THE BRECKENRIDGE DISTRICT.

SUMMARY OF GEOLOGIC HISTORY.

The geologic history of the district, so far as it is known, has been incorporated into the preceding pages. A brief narrative recapitulation of it, however, may help to leave a clear impression of the salient events fresh in the mind of the reader.

During the Paleozoic era the area corresponding to the Breckenridge district was at the southwest end of an island or peninsula of pre-Cambrian crystalline rocks. These were being worn down by active erosion and their débris helped to build up the thick series of generally arenaceous, shallow-water sediments on the subsiding sea bottom to the south and west, particularly the "Weber" and Maroon formations. Through the long lapse of time represented by this sedimentation the pre-Cambrian rocks of the land area were eroded nearly to sea level and probably were also slowly sinking in company with the neighboring sea floor.

In the Triassic period, or possibly as early as the Permian, the sea began to creep northward over the site of the future Breckenridge, depositing as it advanced the red "Wyoming" sediments. By the time the shore had encroached about 2 miles north of the site where the town now stands the remaining land in this particualr region evidently stood barely above water, and as subsidence or submergence continued the Dakota phase of sedimentation overlapped on the worn pre-Cambrian rocks and covered them with a deposit of light-colored sands and gray, in part calcareous muds to a depth of 200 to 300 feet.

The transgression of the sea may not have been wholly uniform, for the Jurassic and Lower Cretaceous are not certainly represented in the Breckenridge stratigraphic section, and although the beds from the "Sawatch" quartzite to the Upper Cretaceous shale appear to have been laid down in undisturbed succession the possibility of there being an unconformity between the "Wyoming" and the Dakota, and perhaps elsewhere in the series, should not be overlooked.

The waters in which were deposited the comparatively clean arenaceous sediments of the Dakota were succeeded by a shallow muddy sea on whose slowly sinking bed accumulated a great thickness of dark, more or less carbonaceous muds with subordinate layers of sand and of impure carbonate of lime. The rather scanty faunal remains preserved in these silts show that they range through the Benton and Niobrara divisions of the Upper Cretaceous and perhaps continue up into the Montana. This predominantly shaly deposit accumulated to a thickness of over 3,000 feet and was doubtless covered in turn by other beds of which no local record remains, as they have been removed by erosion.

The great diastrophic movements at the close of the Cretaceous period put an end to marine sedimentation in the Cordilleran region. It was probably during this revolutionary epoch that the porphyries were intruded, the beds folded and tilted, and the principal lines of dislocation initiated.

Of events in Tertiary time there is no detailed record. During the early Tertiary, closely following the intrusions but, according to Emmons, antedating the major faulting, the lean precursors of the present ore deposits were formed. Throughout the rest of the period the region was probably subjected to vigorous erosion, in the course of which much concentration of the metals in the upper parts of the veins was effected by downward-moving atmospheric waters, the major features of the present topography were carved, and considerable gold from the veins accumulated in the gravels along the larger streams.

Of the first advance of the ice in the Quaternary period no direct record remains in the vicinity of Breckenridge, but the extensive deposits of coarse gravel, the terrace gravels, which formerly clogged the comparatively broad valley of the Blue, are explained as a valley train deposited in front of the ice of this earlier stage of glaciation. Whatever morainal material was left by the first glaciation has been eroded away or was covered by the deposits of the second advance. There must have been considerable erosion between the two glacial maxima, for the moraines and valley trains of the second epoch occupy valleys which in most places had been cut through the older gravels. The principal streams of the interglacial stage appear indeed not only to have cut down to bedrock but to have made some progress in deepening their rocky channels before they were again interrupted and overladen with detritus by the second epoch of glaciation.

Since the last retreat of the ice the topography has not been greatly modified. The streams have gashed the terminal moraines and have incised narrow ribbon-like flood plains in the low-level gravels of the younger valley train.

FUTURE OF THE DISTRICT.

It can not be truly said that the Breckenridge district gives definite promise of any general and permanent revival of deep mining. In fact, at no time in the history of the district has ore been taken from workings such as would elsewhere pass for deep, and at no time has the scale of mining operations been really large. The hope, sometimes expressed and more than once acted on in the past, that the same limestones so enormously productive at Leadville may be found somewhere in the district underneath the younger rocks is dispelled by the demonstrable disappearance of the Paleozoic formations northward and the overlap of the Dakota on the pre-Cambrian. Although excellent ore has been taken from replacement deposits in Gibson and Shock hills the beds containing these deposits are thin and the ore apparently is low in grade below the zone of oxidation. The known deposits have never been of a kind to justify mining on an extensive scale, and even should new deposits of this character be found it is not likely that they would yield ore in large quantities. There are no calcareous beds in the district of sufficient thickness and extent for the development of large deposits by metasomatic replacement.

The Farncomb Hill veins have been virtually exhausted. Although lessees will probably find small pockets occasionally, this locality holds out no encouragement for extensive work. At their best the veins were exploitable only on a small scale and they are so narrow that the presence of extraordinarily rich ore alone can make them profitable. There is a possibility that similar veins may be found elsewhere in the shale near some body of porphyry, but placer operations have nowhere else indicated such remarkable convergence of rich detrital deposits toward one locality as has occurred at Farncomb Hill.

Of the veins belonging to the zinc-lead-silver-gold series a considerable number have proved minable only in their upper enriched portions. Some of these may perhaps in future be reopened and made productive by improved methods of mining and milling, but this is problematic. Another unfortunate feature of these deposits is that they may contain excellent ore in one of the flat-lying masses of monzonite porphyry but be worthless in the underlying shale or quartzite. In other words, the dependence of ore on kind of country rock, taken in connection with the many lithologic changes generally revealed by deep vertical exploration, is an adverse factor to be reckoned with in addition to the depreciation of the ores below a depth of a few hundred feet. This feature also enters fully as much into the evaluation of the deposits of the gold-silver-lead series as of the lodes exemplified by the Mineral Hill group.

Against these general disadvantages may be set off some more hopeful considerations. A few of the zinc-lead-silver-gold veins, especially those in the Wellington mine, undoubtedly contain a large quantity of good ore within a distance of 400 feet from the surface. The problem of working successfully the low-grade deposits of the Jessie and Cashier type does not appear to have been adequately grasped, past efforts having been directed mainly to the finding and stoping of relatively rich streaks, the ore from which was apparently milled by rather crude methods. Finally, in a district where concentration of the metals has taken place at so many points as at Breckenridge it is very unlikely that all the deposits are known or that there is no longer any opening for the prospector. It is safe to predict that discovery of additional ore bodies will at some time infuse new life into the mining industry of this district.

In the districts east of Breckenridge, especially in the Silver Plume and Empire districts, there are important veins in the pre-Cambrian rocks. This fact, as well as the occurrence of the Laurium vein and of the gold-bearing veins at the head of the Blue, suggests the possibility that some of the known veins of the Breckenridge district may carry ore in the ancient crystalline rocks, far below their now visible portions. The indications are, however, that the veins in the pre-Cambrian would be smaller than in the rocks above and, having been unaffected by enrichment, would be of low grade. An attempt to follow a vein from the sedimentary rocks and porphyries through a lean zone down into the pre-Cambrian in the hope of finding ore would probably be disappointing.

The rich gulch washings and the most auriferous spots in the terrace gravels have been practically worked out, but there still remains much low-grade bench gravel that may at some time be washed or dredged, although few data are available regarding the tenor of this material. Dredging of the deep channels of interglacial, and perhaps in part of preglacial time has of late years become an important and profitable industry. How long it will last, even at the present rate of progress with three or four dredges no one can say; but the available gravels are evidently exhaustible and an optimistic estimate of the life of the industry, with four boats in steady operation, could hardly concede it more than 10 years, or 15 years at the most. More powerful dredges than those in use might, by lowering costs, increase the available reserves of gravel, although of course this would be partly offset, so far as the life of the industry is concerned, by an increase in the rate of exhaustion.

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