DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER 77

GEOLOGY AND ORE DEPOSITS

OF THE

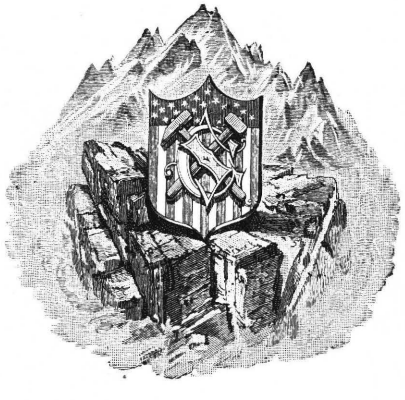
PARK CITY DISTRICT, UTAH

BY

JOHN MASON BOUTWELL

WITH CONTRIBUTIONS BY

LESTER HOOD WOOLSEY



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U. S. GEOLOGICAL SURVEY
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KEY TO LOCATIONS

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Shaft	A-7	39-1
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Daly		
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Tunnel	A-5	40-2
Valeo		
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KEY TO NUMBERS

NUMBER	NAME
1-1	Ontario discovery
1-2	" shaft No. 2
1-3	" shaft No. 3
1-4	" drain tunnel
1-5	" work tunnel
2-1	Silver King Coalition, Silver King shaft
2-2	" " " Massachusetts shaft
2-3	" " " Mayflower shaft
2-4	" " " Alliance tunnel
2-5	" " " Northland incline
2-6	" " " Friga tunnel
3-1	Daly West shaft
3-2	Quincy shaft
4-1	Daly shaft No. 1
4-2	" shaft No. 2
5-1	Daly-Judge shaft
5-2	" " work tunnel
5-3	" " Jones-Bonanza shaft
6-1	Hanauer tunnel
6-2	Crescent
6-3	Apex
7-1	Silver King Consolidated shaft (Bogan)
8-1	California main tunnel
8-2	" shop tunnel
9-1	South Quincy
10-1	Constellation shaft
11-1	Comstock shaft
12-1	Glencoe main tunnel
12-2	" upper tunnel
13-1	Flagstaff
14-1	Hawkeye shaft
15-1	Jupiter
16-1	Little Bell shaft
17-1	Lucky Bill shaft
18-1	Parley's Park shaft
19-1	Wabash shaft
20-1	Superior lower tunnel
20-2	" middle tunnel
20-3	" shaft
21-1	Clarissa incline
22-1	Valeo upper tunnel
22-2	" middle tunnel
22-3	" main tunnel
23-1	Naildriver shaft
23-2	" tunnel
24-1	Wasatch tunnel
25-1	West Ontario
26	East Valeo
27	Cincinnati shaft
28-1	Dutch Canyon tunnel
28-2	" " incline
29	Park City and Tug of War
30	Avandle tunnel
31	Homestake shaft
31-1	" tunnel
32	New York shaft
33	Sunnyside
34	Balmount shaft
34-1	Balmount Atlanta tunnel
35	Silver King Consolidated, Cumberland incline
36	Liberty tunnel
37-1	Tattersall main tunnel
37-2	" shaft
37-3	" prospect
38-1	Woodside shaft
38-2	" lower tunnel
38-3	" upper prospects
39-1	Creole shaft
39-2	" tunnel
40-1	Thaynes Canyon Consolidated incline
40-2	" " " " tunnel
41	Oldham tunnel
42-1	East St. Louis tunnel
42-2	" " " upper tunnel
43	St. Louis-Ontario shaft
44-1	Keystone shaft
44-2	" tunnels
45	Summit Extension shaft
45-1	" " incline
46	J. A. C. tunnel
47	American Flag shaft
47-1	" " Thunderer tunnel
47-2	" " prospects
48	Silver Coin
49	West Quincy

E. M. Douglas, Geographer in charge.
Triangulation by Pearson Chapman.
Topography by Pearson Chapman and J. F. McBeth.
Surveyed in 1901.

ENGRAVED MAP, 1903 BY U.S.G.S.

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TOPOGRAPHIC MAP OF PARK CITY DISTRICT, UTAH, WITH INDEX SHOWING POSITION OF MINES

Scale 1/25000

1 Mile

1 Kilometer

Contour interval 50 feet.

Datum is mean sea level.

(The elevations on this map were later found to be 11 feet too high)

1912

GEOLOGY AND ORE DEPOSITS OF THE PARK CITY DISTRICT, UTAH.

By J. M. BOUTWELL, with contributions by L. H. WOOLSEY.

INTRODUCTION.

The Park City district has won high standing as a "bonanza camp" by yielding large amounts of rich lead-silver ore, and its extensive mines rank well among the dividend-paying argentiferous lead mines of the world.

During the field season of 1901 two detailed topographic maps of parts of the Park City district were prepared for the United States Geological Survey, under the direction of E. M. Douglas, geographer in charge, by Pearson Chapman and J. F. McBeth. The general map, showing an area of approximately 32¼ square miles on a scale of 3 inches to 1 mile, embraces the general area within which the mining operations of this district have been conducted. This map has been published on a somewhat smaller scale and is reproduced as Plate I of this report. The other map, on a scale of 1 inch to 1,000 feet or 5.2 inches to a mile, includes only that part of this area which lies near the largest producing mines. This map forms the base of Plate XXXIX (p. 132).

In 1902 a detailed study of the areal and economic geology of this mining district was begun under the general supervision of S. F. Emmons, then geologist in charge of metalliferous deposits, by J. D. Irving and J. M. Boutwell, the latter taking the field at the close of July and being joined by Dr. Irving about the middle of August. Later Dr. Irving withdrew from the work in order to accept a university appointment, but the writer continued field work until late in December.

Early in August, 1903, detailed mapping was again taken up, and it was completed late in the fall, when the underground study of the geology of the ore deposits was begun and continued until late in February. In the work of that season the writer was efficiently assisted by L. H. Woolsey and, for about seven weeks toward the close of the year, by A. M. Rock. The examination of the ore deposits was resumed in the succeeding field season and completed in December of that year (1904) with the continued assistance of L. H. Woolsey, and, after he left the field, near the close of the season, by H. T. Boutwell. Since that date the writer has kept in touch with developments by hasty visits to view recent discoveries and by correspondence.

This survey was the first systematic work undertaken in this geologic province since the Geological Exploration of the Fortieth Parallel, in 1869, and was the first detailed geologic examination of a wide area in the Wasatch Range. Hence, an unusual amount of general geologic work in the region surrounding the special field was required to establish fundamental geologic facts. Thus, the general geology of the range along the main divide on the west of the eastern slope, and of adjacent parts of the Uinta Range, was studied in reconnaissance, and subsequently that of the Coalville quadrangle, coinciding with a part of the Park City district and embracing the area between the Wasatch and Uinta ranges. The geology and ore deposits in this province, in the neighboring camps along the main divide, in Little Cottonwood, Big Cottonwood, American Fork, and Snake Creek canyons were studied, stratigraphic sections were measured and correlated in Big Cottonwood and Echo canyons, and reconnaissances were made at two points in the southern portion of the Wasatch Range.

Delay in digesting this large mass of facts and in preparing the final report, which is regretted by none more deeply than by the writer, has been caused mainly by the interference of other work. This includes the completion of previous work, occupying two office seasons after the Park City field work was started, the organization of statistical work on the production of lead, zinc, and quicksilver, both in field and office, and two outside examinations undertaken with the consent of the proper Survey officers. Fortunately the resulting loss has not been so serious as it would have been in most districts, owing to a lull in mining operations in this camp which leaves the examination practically up to date, and it has been further minimized by the publication of three progress reports, in 1903, 1904, and 1905, and a paper on "Stratigraphy and structure of Park City district," in 1907, which together have rendered the essential facts and conclusions available for immediate use.

Early in the season of 1903 C. D. Walcott, then Director of the Survey, visited the party on his way to and from the field of his special investigations in a neighboring range, and later C. W. Hayes, geologist in charge of geology, spent a few days in the district investigating some of the problems under consideration.

To Mr. S. F. Emmons, upon whose recommendation and under whose supervision the investigation was undertaken, and to Mr. Waldemar Lindgren, who, having since been in charge of the mining geology of the Survey, has most kindly and wisely directed the completion of the report, the writer expresses his gratitude. The loss to the work through its early relinquishment by Dr. Irving can not be measured, and the personal association with him and his cooperation in the early stages of the field work are deeply appreciated. The survey of the Silver King special area by plane table, alidade, and rod, as he suggested, was, so far as known, the first application on any considerable scale of precise engineering methods to geologic mapping.

To Mr. L. H. Woolsey for his zealous, faithful, and efficient assistance in the field and office during the years 1903 and 1904, the writer gives his hearty thanks. The microscopic examination of the igneous rocks, the study of the glacial and other Quaternary features of the district, and the preparation of the sections of the report dealing with those subjects, together with portions of the section on history of the mining industry, are his special contributions. For paleontologic work the writer is indebted to Dr. T. W. Stanton, geologist in charge of paleontology and stratigraphic geology, who devoted 10 days to field study of certain questions of stratigraphic and paleontologic correlation, with valuable results, and to Dr. G. H. Girty, who made the paleontologic determinations of the large collections of fossils submitted by the writer and has most obligingly and helpfully interpreted paleontologic evidence throughout the work. Dr. Girty has kindly prepared the two plates showing characteristic fossils of the important formations, together with the plate descriptions.

Thanks are due to Dr. W. F. Hillebrand for complete analyses of igneous rocks, to Mr. George Steiger and Dr. E. C. Sullivan for partial rock and mineral analyses, and to Dr. W. T. Schaller for mineral tests. The courtesy, genuine interest, and cordial cooperation shown by all mine owners and operators in freely furnishing data and lending every necessary aid to facilitate the examination of their properties are most gratefully acknowledged. In this general obligation the writer is happy to mention especially Mr. W. V. Rice; Messrs. David Keith, Thomas Kearns, Michael Dailey, and William Lamb, of the Silver King Mining Co.; Messrs. J. A. Bamberger, Ernest Bamberger, John Kirby, and F. W. Sherman, of the Daly-West Co.; Messrs. J. J. Daly, G. W. Lambourne, and John McSorley, of the Daly-Judge Co.; Messrs. C. L. Rood, O. A. Palmer, Matt Connolly, and Alex. Moffat, of the Ontario and Daly companies; and Messrs. W. W. Armstrong and Charles Heath, of the Park City Bank.

GEOGRAPHY.

Park City is situated on the eastern slope of the Wasatch Range, in the north-central part of Utah (fig. 1). It lies about 25 miles southeast of and 3,000 feet above Salt Lake City, its elevation being 7,200 feet above sea level. Located on the southern edge of a high-lying mountain prairie at the junction of three great canyons which there descend to the prairie from the main range, this thriving town has a position of rare commercial value. Its population in 1910 was

3,439. A branch line of the Denver & Rio Grande Railroad unites it by way of Parleys Park with Salt Lake City (35 miles), and a branch line of the Union Pacific Railroad extends from the main line at Echo (28 miles). It thus forms a most convenient outlet point for the producing mines of the district, which are located on the slopes of the canyons that rise from this point southward.

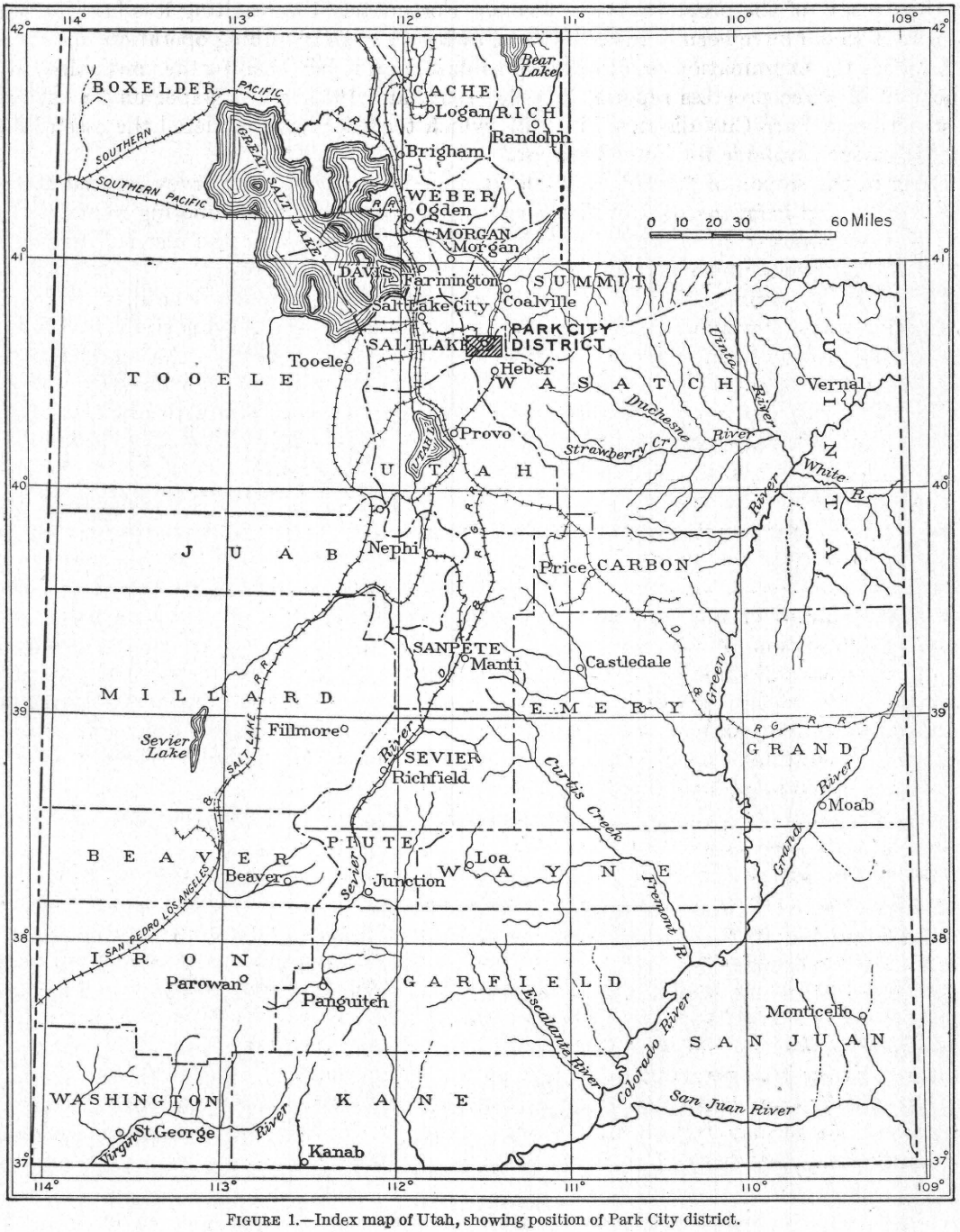

FIGURE 1.—Index map of Utah, showing position of Park City district.

The Park City district embraces a tract that lies between the precipitous walls of barren rock, inaccessible cliffs, and ledges that mark the crest of the main range on the west and the verdant mountain meadows of Heber, Kamas, and Parleys, along its eastern foothills. This intermediate belt lies upon the northern part of a prominent spur which stretches from Clayton Peak, in the main range, toward the east. This spur forms the headward portion of East Canyon,

divides the Weber from the Provo, and is the connecting link between the Wasatch Range and the Uinta uplift. It comprises three topographical divisions—a steep slope southward, which overlooks an extensive, relatively level tract farther south, called Bonanza Flat; a gradual descent northward, which is deeply cut by four narrow, steep-sided gulches, Thaynes, Woodside, Empire, and Ontario; and a long, steep, deeply incised slope eastward, which unites the Park City upland with the prairie belt.

The climate is remarkably bracing, with short, cool summers, short autumns, and long, rigorous winters marked by heavy snowfalls and low temperature. Being on the protected, sunny side of the range, however, it escapes much of the harshness that neighboring canyons suffer. Water, although hardly abundant, is not scarce. Springs and watercourses cut by underground workings yield a constant supply the year round, and natural rock basins at the foot of the pinnacle of Clayton Peak are utilized as reservoirs. A supply of water that is sufficient for domestic purposes is obtained from the Alliance tunnel, and the outflow from the Ontario drain tunnel, which is generally believed to include the drainage from a large portion of the great mines, furnishes the power for the Park City electric-light plant. Although the slopes originally supported a growth of pine 3 to 5 feet in diameter, this was early utilized for underground timber. At the present day little heavy timber remains standing, though a considerable grove of evergreens still hides in the protected amphitheater at the head of Empire Canyon above the Daly-Judge shaft, and some rather large cottonwood trees rise from the bottoms along the larger creeks at the extreme southeast. Young aspen is the most common growth and flourishes on the canyon slopes throughout the district. The higher divides, such as Clayton Peak, support patches of scrubby evergreens. Fuel is supplied from extensive veins of good coal at Coalville, 28 miles farther north, and from the forest growth on distant parts of the Wasatch and Uinta ranges.

HISTORY AND DEVELOPMENT OF THE MINING INDUSTRY.

EARLY CONDITIONS.

The history of the Park City district is essentially that of its mines, and the discovery of the ore deposits is bound up with events occurring at the time of the settlement of Salt Lake valley, a brief account of which will aid in giving a better understanding of subsequent developments.

Scarcely more than 60 years ago Salt Lake valley was occupied only by native tribes of Indians who assembled here to gather their winter food of crickets. The region had, indeed, been visited by early Spanish explorers, who sought an elusive sea as far north as Utah Lake; by fur trappers, among whom was James Bridger, who first discovered Great Salt Lake, 90 years ago; and by California immigrants, including Fremont and Kit Carson, who rested a bit in the valley; but it is to the "Latter-day Saints" that we owe not only the early winning of Salt Lake valley to civilization, but also indirectly the disclosure of the mineral resources of the surrounding region. When their weary march across the uninhabited plains and barren mountains in 1847 finally, in the month of July, led the "Saints" to the summit of the Wasatch Range, they looked down with delight upon a fertile meadow. That area, which lies a short distance north of the present town of Park City and is now known as Parleys Park, after one of the Mormon pioneers, is a mountain meadow of considerable extent, lying about 7,000 feet above sea level and well suited for pasturage during the summer months. At that time of the year the park, with its mat of early flowers and expanse of restful green, must have seemed to the wanderers a welcome sign of the long-sought promised land. With renewed hope, therefore, they continued northward, passing by this silent meadow within its wall of hills, following a trail made the previous year by Donner and his company. At the mouth of Echo Canyon they had turned aside from the well-beaten road of California immigrants and traveled southward along Weber River about 12 miles, then crossing into Parleys Park and passing northward over the hills to Emigration Canyon, they finally wound down into the valley of Great Salt Lake.

In this valley, pregnant with the necessities of life—with streams of mountain water tumbling from the canyons which scored its sides, game abundant in its hidden retreats, fuel of

cottonwood and pine to be had for the felling—the "Saints" did their first planting. Here they also founded a city, for the broad plain, though a seemingly barren waste of sagebrush and sunflowers, abounded in possibilities for sustenance. The land on which they settled was then Mexican territory, but it was acquired by the United States in the following year.

In this forced emigration of the "Latter-day Saints" and in the natural advantages of Salt Lake valley lie the primary causes which led to the early colonization of Utah and finally opened its mineral wealth. At that time, however, no one was thinking of mining as an industry. The need of food supplies led these pioneers to take up agriculture first. The same need, it is said, caused the officers of the Mormon Church for a long period to discourage prospecting for precious metals. No doubt, however, this policy was followed partly to prevent the influx of Gentiles, which would surely follow the discovery of gold. It is certain, at any rate, and the fact is significant, that not until the dusty valley had been developed by 15 years of painful effort into the productive fields and orchards of Mormon farmers were the ore-bearing deposits investigated to any extent, and then not by the Mormons. Moreover, though "in 1857, and perhaps at an earlier date, it was known that there were silver mines near Great Salt Lake," [1] it was not until the spirit of self-defense had given way to a state of peaceful industry that serious prospecting was undertaken. The Mormons had been in conflict, first with the forces of nature, then with the Indians, who, though in the beginning friendly, grew jealous of the white man's occupation of their favorite lands. Later, because of alleged contempt of Gentile judges and the officers of territorial government in general, they were arrayed against United States troops. This occurrence took place in 1857 and has been called the Utah War. The Federal expedition under Col. Johnson wintered east of the Wasatch Range, and after peaceful negotiations in the spring of 1858 entered the valley in the month of June. A site for encampment was selected in Cedar Valley, and this, the first military camp in Salt Lake Basin, was called Camp Floyd. Though the unsolicited presence of troops and the untactful acts and speeches of governors and judges kept ill feeling alive, the peaceful surveillance thus established continued until the outbreak of the Civil War, when the garrison was recalled. But the next year, 1862, "ostensibly for protection against Indians, but in fact because the mail and telegraph service were not considered secure in the hands of their regular carriers, and also, perhaps, for the purpose of holding the territory under military supervision," Col. Conner with his California volunteers was ordered to Utah. He arrived in October and after some difficulties with Mormon authorities established Camp Douglas, planting his guns on the brow of an eastern terrace that commanded Salt Lake City.

From this time dates the systematic prospecting for ore in this region. As to the reason why Conner's men began prospecting, authorities differ. Some say that he early saw an immigration of Gentiles to be the solution of the Mormon problem and sought an incentive for it in the discovery of the precious metals. Others believe that the sight of unknown mountains and perhaps hints from the Mormon settlers revived in his men, old California miners as they were, the fever of 1849. At any rate, during peaceful inactivity, squads of men from time to time set out for the mountains on prospecting tours. For some reason, probably through the representations of "George B. Ogilvie, an apostate Mormon, engaged in farming," they turned first toward the Oquirrh Range. Ogilvie had reported to Col. Conner his discovery of mineral in the early fall of 1863 in Bingham Canyon. It was one of these exploring expeditions, under Capt. Heitz, that first revealed argentiferous galena in Bingham Canyon, and on September 17, 1863, Ogilvie and others formally took up here the first mining location in Utah, known as the West Jordan claim. In the following December "the first mining district in the territory was formed and named the West Mountain district. It embraced the entire extent of the Oquirrh Range." (Murphy.)

Among the soldier prospectors, but not of them, was a California miner who had prospected throughout California and Idaho and who had been drawn to prospect in Utah, as he said, "on account of its being so mountainous, like northern California and other territories." This was

[1] Bancroft, H. H., History of Utah, p. 741.

Rector Steen, the destined discoverer of the Ontario mine. All that winter he and others, probably incited by discoveries in Bingham Canyon, prospected through Bingham, East, and the two Cottonwood canyons, but after a fruitless search he went back, in March, 1864, to Montana and Wyoming. The military prospectors, however, were not disheartened. In the same month they established a post called Camp Relief, near the present town of Stockton in Rush Valley, and in the following June seceded from the West Mountain district and formed the Rush Valley mining district.

The composition of the ore discovered and the cost of transportation made it imperative to undertake domestic reduction. The first attempts at smelting were made in the summer of 1864, when Gen. Conner and others erected in Rush Valley, near the present town of Stockton, a furnace of the reverberatory pattern. This was the first smelter in Utah, but it was not suited to the direct reduction of the ores at hand. For this reason primarily, together with the inaccessibility of the country and the great expense of reduction, these early ventures failed. The results obtained were of some value though not commensurate with the outlay, for they not only showed that the ores were easy of reduction but also emphasized the fact that transportation was a necessity. Consequently active mining received a setback and awaited the advent of the Union Pacific Railroad, which had already (1862) been incorporated. But the finding of good ores was sufficient incentive to continue the search. Prospecting went on, therefore, and claims continued to be staked, but attention now turned eastward to the Wasatch Range.

It was in the summer of 1864 that "the first discovery of silver-bearing rock [in the Wasatch Range] was made by Gen. Conner in person at the head of Little Cottonwood Canyon; the first ore encountered was galena and afterwards carbonate of lead, both being found in chimneys." Thereupon the Mountain Lake mining district, covering the backbone of the Wasatch between Provo River and Weber Canyon, was established. During several years following, for reasons above given, little was done toward developing these discoveries. It was not until July, 1868, that the first shipment from the Wasatch Range was made. It consisted of one carload of galena, which was shipped by Walker Bros. from Little Cottonwood Canyon.

The establishment of railway communication during the next two years marked a third epoch in the history of mining in Utah. The Union Pacific was completed in the spring of 1869 and the Utah Central between Ogden and Salt Lake City early in the following year. The second requirement for the full development of the natural resources of this region, namely, transportation, was now supplied and the commercial monopoly and isolation of the Mormons were broken. Anticipating these events, however, the impetus to mining was felt before both railways were completed; practical work toward developing the mineral prospects was begun in the fall of 1868, and during the summer of 1869 it was established beyond doubt that the deposits already discovered were really valuable. The famous Emma mine and the rich Ophir district had then been well opened. The advantages of Utah as a mining field—its facilities for transportation, a food supply from a large agricultural population, and reasonable hope of reward—soon brought an influx of the old pioneer class of prospectors from Nevada, California, Montana, Idaho, and Colorado, who scattered throughout the Wasatch Mountains.

HISTORY OF PARK CITY DISTRICT.

In the fall of 1869 locations in Little Cottonwood Canyon were becoming so numerous that the Little Cottonwood mining district, with very nearly its present boundaries, was cut off from the somewhat extensive Mountain Lake district. Prospectors continued to spread into Big Cottonwood and American Fork and some, crossing the divide at the head of these canyons, first looked down the narrow gulches leading to Parleys Park.

Those unnamed gulches descended to unite in the widening valley, where no builder had yet dreamed of Park City, and where a score of years before the eyes of the weary "Saints" had beheld a restful strip of waving green. But now the early prospectors found evidence of long occupation. Far down the park were sawmills erected in 1853 by Samuel Snyder, the first settler in this locality. Farther south contented cattle browsed on the herd grounds

granted in 1853–1855 to Snyder, H. G. Kimball, and J. M. Grant, and across these fields ran the toll road from Big Canyon to Kamas Prairie, built by Kimball and his partners. This pastoral condition of Parleys Park and its canyons to the south when their peacefulness was first disturbed about 1869 by prospectors is quaintly described by Rector Steen, who though not the earliest was among the early prospectors of this region.

"Parleys Park * * * was a very pretty valley with several ranches scattered over it; and several springs were in the valley." The tents and brush shanties of prospectors, very few indeed, were the first habitations in the lonely canyons, but, thanks to the rural community, provisions were plentiful and reasonably cheap. The following prices, says Steen, were current at the time: "Flour was $4 and $5 per 100 pounds; bacon 30 and 40 cents, beef 25 cents, green coffee 30 to 40 cents per pound; sugar 10 pounds to the dollar; Irish potatoes were 50 cents per bushel; butter only 30 cents per pound." But mining utensils brought better prices: "A pick $5, shovel $2.50." With the necessities of living and of mining—food, water, fuel, and timber—close at hand, prospectors made the first discoveries and locations in the region now known as the Park City mining district.

When the first find was made is not certainly known, but the discovery of the Walker & Webster claim in 1869 by Rufus Walker and the subsequent find of ore in the summer of the same year by Ephraim Hanks are the earliest notices on record.[1] That Hanks was then prospecting in this vicinity is corroborated by notes in the diary of S. F. Emmons, made during his campaign of 1869 in connection with the exploration of the fortieth parallel. As to the first locations in this area information is more definite. The records of the recorders of Wasatch and Summit counties show that the first location was the Easterly Extension of the Young America lode made on December 23, 1868, and that the next four—the Westerly Extension of the Young America lode, the Young America lode, the Yellow Jacket lode, and the Green Monster lode—were made in the following month. The first shipment of ore from this region, called in the records Parleys Park, is said to have been 40 tons for the month of July, 1870, but no mention is made of the mine producing it.[2] Later records, however, place the first shipment to the credit of the Flagstaff mine, in 1871. Rector Steen writes: "I went back to Salt Lake City the fall of 1871 [his second visit to this region] and we discovered a mine we called the Pioneer, * * * from me. We sold this mine to a man by the name of Pierce for $6,000." Raymond, in his report for the same year, notes the Piñon as the chief mine of Parleys Park. As to the early mines, therefore, we must content ourselves with this information; but as to the first producer there is not so much doubt, for the Piñon in 1871 had a large body of galena and carbonate ores, assaying, it is reported, 30 to 250 ounces to the ton,[3] and is said to have contracted to deliver 20 tons a day to a smelter to be erected at Ogden. In the same year the Flagstaff, Walker & Webster, Wild Bill, Rocky Bar, and other prospects were located. All are said to have been lead mines, principally carbonate, in limestone.

The increasing number of locations outgrew the supervision of the Mountain Lake district, which up to that time had included this area, and the Uinta, Snake Creek, and Blue Ledge districts were set off from it. The Uinta district, organized November 18, 1869,[4] was formed first, and the two latter were established in April or May, 1870.[5] All are still in existence, though the office of district recorder has been abolished by law and his duties have been transferred to the county recorder. Parts of these three districts form what is now commonly known as the Park City district. The Uinta district lies in the southern part of Summit County, embracing all the present large mines in the Park City area, whereas the Blue Ledge and Snake Creek districts are in Wasatch County and bound the Uinta district on the east and south, respectively. The earliest locations are still to be read in the old records of these districts, and there will be seen the names of the pioneer prospectors. Simmons, said to be the first man

[1] Park Record files, 1887.
[2] Raymond, R. W., Statistics of mines and mining, 1870, p. 223, quoted from a Salt Lake City correspondent.
[3] Idem, 1871, p. 329.
[4] Letter to writer from county recorder of Summit County, Utah, dated Mar. 22, 1905.
[5] Letter to writer from county recorder of Wasatch County, Utah, dated Mar. 22, 1905.

to discover ore in the Uinta district, Hanks, Snyder, and Stedman, the first recorder of Uinta district, are among the earliest names.

It was about two years after these men had made their first locations that an event occurred which has made this region one of the most noted mining camps of the country, namely, the discovery of the Ontario ledge. After a trip to Arizona in the winter of 1872, Rector Steen returned in the spring to Salt Lake City and made his way back to Parleys Park. He describes this discovery in these words:[1]

> I camped in a brush shanty for six months at the branch just below the Ontario, waiting for the snow to melt off. I went then to what is called the Badger mine, and about the 15th of June, 1872, we discovered the Ontario mine. There stood right near this mine a pine tree, and near by was a fine spring. We camped under this tree and got water from the spring. When we discovered this mine we found a little knob sticking out of the ground about 2 inches. * * * We had the rock assayed and it went from 100 to 400 ounces to the ton. We sold the mine to Hearst and Stanley on the 21st day of August, 1872, for $27,000. My partners were John Kain and Gus McDowell.

Mr. Steen describes the conditions about the locality as follows:

> There was not a house near the mine when we were there. All lived in tents and brush shanties, and very few of them. There was plenty of timber on the hills and all over the country * * * mostly black pine and some cedar.

With the inception of the Ontario began an effort to mine lode ores. In the meantime the Piñon, Walker & Webster, Flagstaff, McHenry, Buckeye, and other mines, some of which were discovered before the Ontario, had opened small ore bodies and had shipped small amounts of marketable ore from time to time, but in comparison with the Ontario, none of them attained a conspicuous place in the annals of Park City mines.

With the coming of men to work the mines the necessity for supplies arose. Owing to the existence near by of a well-developed agricultural community, food was both abundant and cheap, and for this reason, perhaps, Park City has never been a high-wage camp. For shelter log houses were built, which to some extent replaced brush shanties and were the first permanent habitations in the canyons south of Parleys Park. They were not, however, located on the site of the present town, but each group clustered about the shaft of some mine, or near the "discovery." They were simple, one-room affairs, built of unhewn logs felled near by, with small windows, one door, and a fireplace. Some of them are still occupied, and several may be seen to-day nestled midway in Ontario Canyon.

Of the mining supplies, machinery and some other articles had to be hauled either from Salt Lake City, a distance of 35 miles, or from Echo City, 24 miles, but fuel and timber were found in abundance on the surrounding hillsides.

The Marsac Co., having purchased the Flagstaff mine, built a stamp mill during the summer of 1874, and the McHenry Co. built a similar mill during the same season, but from lack of ore neither was largely used that year. The Ontario people then rented the McHenry mill and began to treat ore there in 1875. Later the Marsac mill was also leased, but was abandoned on the completion of the Ontario 40-stamp mill. In the same year the erection of the first concentrator of the camp was begun, with the intention of working over the Ontario tailings. In February, 1876, the Ontario mine alone was producing $14,000 a week, and the whole camp was producing $20,000. About 150 men were employed at both mine and mill, and the mine wages averaged $3.60 a day. In one month the freight on bullion sent to Salt Lake City was $38 and the cost of hauling ore from mine to mill was $390. Although other mines, including the Flagstaff, McHenry, Piñon, and Walker & Webster, continued to produce ore, the bonanza bodies of the Ontario were the ones which gave permanence and steadiness to the silver-mining industry of the camp.

The substantial condition of the Ontario mine soon brought many inquiries concerning business openings in its vicinity. In 1879 the Ontario miners were building homes rapidly near the mine and lower down the canyon at the present site of Park City. There were few buildings to rent. Prospecting was active in the hills, especially in the untried ground east and west of the

[1] Letter from Rector Steen to J. M. Boutwell dated Dec. 10, 1902. Steen was living in Missouri in 1902 in the enjoyment of good health, having left for his old home the day after the Ontario sale.

Ontario. A procession of wagons lined the roads, bringing salt, coal, and other merchandise from Salt Lake City and Coalville. The Salt Lake Herald said: "There is an influx into the camp such as has not been known for some time."

Park City suffered a setback through a fire on December 2, 1882, which destroyed several of the principal buildings of the town, including Fisher's Hotel, the Thiriot Building, the Bank Building, and Wiseman & Clark's. This was only the forerunner of other misfortunes which in the next year marked an interval of business depression following the previous short period of growing prosperity. Among such occurrences may be noted several failures of merchants, the closing of some of the larger prospects, and the passing of the Ontario dividend. The last, however, was due not to deterioration of the mine, but to the foresight of its managers, who were now enlarging its facilities by purchasing contiguous property, coal mines, and the control of the Utah Eastern Railroad and by completing the 600-foot level drain tunnel, so that, although there was some evidence of unstableness, there was also a marked improvement in the conditions which told for the future welfare of the camp.

As prospecting was continued claim lines began to conflict, and claim litigation, one of the curses of mining camps, arose. After long years of legal strife the pioneer mines on Piñon Hill, including the Piñon, Climax, and Rebellion, were finally consolidated in 1882 under the name of the Crescent Mining Co.

The depressed condition of business was finally succeeded by a period of renewed activity. Many mining properties changed hands. The Daly Co. began work on the western extension of the Ontario vein; the tramway from the Crescent mine to the town was finished, and three or four small producers swelled the shipments of the camp. This renewed activity was enhanced by an advance in the metal market which aroused many old and abandoned mines carrying low-grade ore. As a result the producing area outside of the Ontario-Daly properties, which had hitherto been restricted to Crescent Ridge, became centered on Treasure Hill; the latter area was thenceforth to grow and to rival in production the Ontario-Daly vein. For some years longer lode mining was still to continue, but the activity on Treasure Hill was the beginning of mining bedded ores. This phase of the industry, though waning, still continues. In 1888 lode mining was given new life by the owners of the Ontario mine when they began its 3-mile drain tunnel, in order to reduce considerably the expense of mining. This example was followed by the owners of the Anchor and Alliance mines, who also began work on long drain tunnels. Lode mining was further aided by the passage of the new law by Congress on July 14 providing for the purchase of 4,500,000 ounces of silver a month, which resulted in a great improvement of the silver market. The influence of this law brought about an increased tonnage in Utah mines and a general tone of prosperity throughout the mining camp.

In 1892, however, silver dropped to 83 cents an ounce—the greatest decline then on record. The effect on the annual output of Summit County was scarcely noticed owing to the advent of two new producers, the Silver King and Mayflower; but it was seen in the passing of the Ontario dividend and among the small mines in the closing of the Crescent, Woodside, and Daly West.

In the following year, 1893, occurred a further drop in the price of silver from 83 to 70 cents. The rapidity of the fall was due to the passage of an act by the British Parliament which closed the mints of India to the free coinage of silver and to the repeal in November of the purchasing clause of the act of Congress referred to above. But the real cause of the fall is much more general. With a few fluctuations silver had declined steadily since 1872, owing to the increase in supply and decrease in demand. To resist the action of the natural law thus operating, artificial means were used in the form of various legislative acts. These did not produce the desired improvement, but by holding back the natural working of this law only made the crash greater and more sudden when it came.

Following the price of silver, the production of the metal in Utah steadily decreased after 1891, but that of Park City curiously increased till 1893, when it suddenly fell off. All the mines of Park City were affected in the same way and worked only intermittently during the year; even the Ontario-Daly, which in 1892 was producing nearly three-fourths of the Park City product, fell off one-third. Such a year as 1893 was naturally discouraging for young shippers

such as the Daly West, Silver King, and other Treasure Hill mines. This year marked the beginning of an epoch of cheaper methods, of more effective saving of values, of relief from water, and of realizing from other metals besides silver. These improved methods have aided greatly in raising the output of the camp to its present high figure.

In 1897 the price of silver dropped to 54 cents. In consequence the Daly West and Ontario mines closed down, but the silver-lead producers, of which the Silver King was the leader, were able to withstand the low metal market. Lower prices stimulated further the development of economical methods of mining and reduction. Large concentration mills were erected, giving increased capacity for the treatment of low-grade ores. Further, in 1901, valuable bodies of rich smelting ore were discovered in Quincy ground, which quickly placed that property at the head of the list of producers, and the camp again assumed the lead in the production of silver in Utah, which it had held in 1895.

The chief events of the last decade will be found in the detailed descriptions of the respective mines. In general, the period has been one of mining rich bedded ore and lode ore of milling grade, attended by a progressive reduction of costs and the return of good profits varying with the broad movements of the metal market. With the gradual depletion of the bonanza-bedded ores in some properties, large bodies of low-grade ore have been developed in deep-lying fracture zones. The future character of the industry in the Park City area will depend upon whether important bedded ore bodies are discovered tending to continue present methods or whether additional bodies of milling ore are developed requiring more reliance upon concentration.

MINING.

The development of this district has been marked from the outset by a broad, far-sighted policy. The early proof of the great extent and high value of the ore bodies encouraged large expenditures for the best means of exploitation. Great workings have been systematically opened and an immense quantity of ore has been economically mined and scientifically reduced. The rapid and successful development of the mines has been accompanied by the growth of a prosperous and well-regulated community.

Many difficult problems have demanded solution, especially those arising from the necessity for water and power and for deep and extensive development, mine drainage, uninterrupted transportation of supplies, a large output of ore at all seasons, and maintenance of proper conditions of living.

WATER AND POWER.

Mountain lakes, springs, and mine openings afford sufficient and excellent water. An ample supply for city use comes from the drainage basin of Walker & Webster Gulch through the Alliance mine drain tunnel to three small reservoirs in Empire Canyon, whence it is distributed through underground mains for fire and private service. A large part of the city supply was formerly piped from the spring on the lower northern slope of Crescent Ridge just northwest of the Bogan shaft.

The water that collects in several small rock basins at the foot of Clayton Peak is piped thence to the Daly West and Ontario mines, 2½ and 3½ miles away, respectively. This supply is sufficient for domestic use, for developing power, and for the concentration mills. A small additional supply is obtained for the Daly West mine from the Lady Morgan Lakes, two small ponds dammed back in the gully just west of that mine by a high moraine. For several years all the water required at the Silver King mine and boarding house was piped from the Henrietta tunnel at the head of Thaynes Canyon over Crescent Ridge to tanks at the company's plant. In 1903 an additional supply was obtained by siphoning part of the outflow from Alliance tunnel up several hundred feet over the ridge to the north and thence to the Silver King plant. The Daly-Judge mill runs on a portion of the flow from the Daly-Judge drain and work tunnel. Springs and creeks suffice for the needs of smaller and isolated properties.

This water supply is nowhere collected in sufficient volume to afford power directly, but the discharge of the Ontario drain tunnel, which varies from 6,000 to 9,000 gallons a minute, is

utilized for developing electric power. At the mouth of the drain tunnel, about 3 miles east of Park City, this outflow is collected in a small reservoir, whence it falls about 125 feet and is delivered through one 2½ and one 2¾ inch nozzle to two Pelton wheels about 3 feet in diameter. The 72 horsepower thus produced runs separately two alternating-current generators, which develop a voltage of 2,500 loaded and two bipolar generators, which develop a voltage of 125. This power lights Park City and the works of the Ontario Co. The power for the Silver King plant is supplied by a 125-horsepower Corliss engine for the sampler, a 150-horsepower Corliss for the mill and lights, a reserve 90-horsepower engine for exciting the dynamo and for light millwork, a hoisting engine, and a compound engine for driving the air compressor. The Daly West plant has a Corliss hoisting engine, a compound Corliss engine for the air compressor, and one 160 and one 100 horsepower dynamo for the mill. The electric lighting uses 30 horsepower from the smaller dynamo. In the similar equipment of the Ontario plant the power transmitted from the Ontario power house at the mouth of the drain tunnel is used wherever feasible. On smaller properties various methods of developing power have been followed, a gasoline hoist being the only machine used by some.

MINE WORKINGS.

The mine workings lie in two great parallel northeast-southwest belts and are entered through both deep shafts and long tunnels. More than 20 shafts now accessible have reached a depth of at least 500 feet, 10 a depth of at least 1,000 feet, 6 a depth of at least 1,300 feet, 3 a depth of more than 1,500 feet, and 1 a depth of 2,000 feet.

The northern belt, embracing the Woodside, Mayflower, Silver King, and Kearns-Keith properties, is entered by shafts and by two long tunnels—the Hanauer and Alliance; the southern belt, including the Ontario, Daly, Daly West, Daly-Judge, and Little Bell properties, is entered by shafts and three long tunnels—the Ontario drain tunnel, the main Ontario-Daly-Daly West work tunnel, and the Daly-Judge drain tunnel. The adjoining mines are connected so that it is possible to pass continuously underground from one end to the other of each belt, the distance in the southern belt being over 5 miles. Furthermore, a crosscut somewhat over 450 feet long would unite the two great belts, thus connecting all the great mines in the district. The aggregate length of underground workings in the district is probably over 100 miles.

This great volume of excavation has been made expeditiously, safely, and economically. Machine drills driven by compressed air are used for exploratory and dead work in nearly all the important properties. In the majority of plants air is compressed by compound Corliss engines and transmitted underground through iron pipes to working faces. Its efficiency is increased in these properties by introducing receivers at suitable depths and distances. Air transmitted underground from the collar of the Silver King shaft to the face of the Alliance tunnel, over 10,000 feet, is there effective. The machine drills are those operated by one or by two men and the X pattern is used exclusively. When it is desired to drive a large tunnel rapidly, as in the recent extension of the Ontario drain into Daly West ground, two machines, each manned by two experienced men, are set up on the same bar and operated at the same time. For breaking ore and for developing small properties hand drills and single jacks are used. The usual methods and means of shooting are employed except in some special cases for which 5 X caps and German fuse are adopted.

Stoping is done by the overhand method, both on beds of replacement ore of gentle dip and on veins of steep dip. In neither type have the bodies proved to be thick enough to allow stoping by the caving system. Timbering in the largest stopes, as in the lower levels on the Daly West vein and in the main fracture in the Silver King, is by the square-set system. More frequently, however, the chambers on the fissures are so narrow that props suffice, and the stopes on beds are usually low enough to permit props and cribs.

In the early days the slopes adjacent to the mines afforded an ample supply of admirable timber of even the largest dimensions. Later the great demand exhausted the local supply and the timber lands of the adjacent Uinta Range were drawn from. At present much of the mine timber is brought from Oregon.

In 1903 accidents in two of the large mines by caving led to an inquiry as to whether sufficient and proper timbering was regularly done. It was concluded that the injuries had resulted from personal negligence on the part of the miners rather than from lack of adequate timbering by the companies. In general the mine superintendents and others in charge feel the responsibility of safeguarding the lives of their men and maintaining the mines intrusted to them in proper condition.

TRANSPORTATION.

The extensive exploration, the large quantities of ore mined, and the distances of the mines from loading railway stations have required the solution of many problems of transportation. Ore broken sufficiently small is dropped from stopes through inclined chutes to the work level, "in one instance for a distance of 300 feet continuously," and trammed either to the mouth of a tunnel or to the work shaft, where it is hoisted to the surface for treatment or shipment. Waste is utilized in filling worked-out stopes or is dropped to the work level, trammed to a hoist, and raised to surface dumps.

From the Silver King mine the ore and concentrates are conveyed to the loading station in Park City by an aerial tramway. This tramway is of the Finlayson pattern, 7,300 feet in length, and is strung over 39 steel towers ranging from 16 to 65 feet high. It carries 80 buckets, each having a working capacity of 500 pounds of ore or 325 pounds of coal, which are attached to the cable (long lay) at intervals of 172 feet; the normal speed is 150 feet a minute. Loading is done by one man and unloading at the lower terminal is automatic, the ore falling directly into freight cars. On the return the buckets bring all the coal used at the mine, mill, and boarding house. The total fall from mine to lower terminal is 1,000 feet and despite a steep rise at the head allows the buckets of ore to be propelled by gravity, but when coal is returned a little additional power is required. From the bins near the sampler coal is carried to the various works on the property largely automatically. Shipping by this method has proved very satisfactory and the cost averages from 17 to 22 cents a ton.

The work tunnel from the Daly West, Daly, and Ontario mines, by which ore is trammed on horse trains to the loading station at Park City, is about 2½ miles long. It embraces parts of the mine workings in these properties, which have been reopened, and substantially timbered and tracked for this heavy tramming. For a mile at the outer end the 600-foot level drain tunnel of the Ontario Co. is utilized. For the privilege of shipping through this and the Daly property, the Daly West Mining Co. pays the Ontario Co. a royalty of 10 cents a ton. The cost of shipping by this method could not be ascertained. The method possesses the advantage of perfect protection from the weather which, in a region like Park City that is subject to frequent deep snowfalls in winter, is an important aid in providing uninterrupted transportation.

Both crude ore and concentrates are weighed and loaded on freight cars at the loading station, and then go to smelters over a standard-gage road.

DRAINAGE AND VENTILATION.

The most serious difficulty encountered in developing the mines of this district has been an immense amount of underground water. Extensive drainage works, the construction of which has demanded high engineering skill, persistent labor, and the outlay of enormous sums of money, testify to the continuous and strenuous efforts which have been required to contend with this almost insuperable obstacle. Success has been attained, however, and at present within the principal mining area water is handled without much expense, except on those levels which are below the main drainage tunnels. Recent sinking on ground near the border of this area, as in the J. I. C. and Silver King Consolidated properties, has revealed quantities of water which render credible the reports of flows encountered in the early days before the ground had been well drained.

The region is subject to heavy precipitation, and the rocks, especially the red shale and massive quartzite, hold water in great quantities. The first mines to penetrate this water-

laden ground to any depth were the McHenry and Hawkeye workings in McHenry Canyon and the No. 1 and No. 2 shafts of the Ontario in Ontario Canyon. The struggles in those early days against water seem almost incredible, as on the levels which were then so wet one finds now only dust. In 1881 they led the Ontario, which was then using 127 tons of coal for developing power for pumping, to run a long-drain tunnel on the 600-foot level. This tunnel was driven from the Ontario mill 6,357 feet to the No. 3 shaft and 500 feet beyond this point, thence 2,700 feet west to the Daly line. It now extends through Daly ground to the Daly West shaft. This tunnel effectually drained the adjoining ground to the depth of 600 feet.

The enormous flow which continued to be encountered at greater depths is indicated by the installation at the No. 3 works of a powerful Cornish pump, the largest in use at that time in the West. The flywheel was 30 feet in diameter and weighed 70 tons. The pumps were 20 inches in diameter, had a 10-foot stroke, and were capable of throwing 320 gallons of water at each stroke. The pump rod, of Oregon pine, was 1,060 feet long and 16 inches square, and its several sections were united by iron strapping plates 1 by 10 and 1 by 12 inches 30 feet long, The pump lifted 2,560 gallons a minute, 153,600 gallons an hour, or 3,686,400 gallons a day from the 1,000-foot level to the drain tunnel on the 600-foot level.

But development progressed to depths below the reach of this powerful machine, and late in the summer of 1888, the construction of a great tunnel which would drain the mine to a depth of 1,500 feet at the No. 3 shaft was undertaken. An outlet sufficiently low to drain this level was located on the eastern slope of the range about 3 miles east from the mine. The dimensions of the tunnel are, height 9 feet, width at top 4 feet, and at bottom 5 feet. The water ditch is 21 inches deep and has a capacity of 13,000 gallons per minute; its grade is one-half inch to a rod. The tunnel was timbered with 10 by 10's, a heavy plank flooring was laid over the ditch and on this a track of 18-pound rails. In several stretches the ground was so bad that all ordinary means for working failed. The ordinary spiling and breast boards proved useless; advance could be made only with spiles of selected timber shod and capped with iron and driven home with compressed air, and to prevent the rock walls from starting on the spiling huge sacks of hay were packed behind it. It is stated that frequently 40 to 50 carloads of loose ground would escape through a crevice only as large as a man's hand, and startling accounts of the size and power of water flows which were tapped are related. Parts of the bad swelling ground cost $3,500 a foot. The tunnel is 15,490 feet in length and absolutely straight, so that a person standing at the face is able to see daylight at the mouth nearly 3 miles distant. Connection between the part driven from the mouth and that driven from the No. 2 shaft was effected Sunday night October 7, 1894. The total cost of the tunnel was about $400,000, and the entire construction was accomplished with the loss of only one life.

At present writing, more than ten years after its completion, the tunnel yields a flow of 6,000 to 9,000 gallons a minute, varying according to the season. This flow is commonly believed to include the greater part of the drainage from the area embracing the large mines. The Daly drains with the Ontario as a part of that mine; the Daly West, the next removed and adjoining the Daly, lies in the same fracture zone and drainage area. The Daly-Judge, next southwest and at the farthest end of this zone, has always been a very wet mine. In 1886, when the shaft was at a depth between 300 and 400 feet, the water was so abundant that two pumps were barely sufficient to keep it down, and later in that year it rose nearly to the surface. After an energetic campaign of pumping with newly installed pumps had been carried on for a year longer, a deep drain tunnel was started on August 12, 1887. This was driven from a point in Empire Gulch, opposite the mouth of Walker & Webster Gulch, southwesterly toward the Anchor shaft and in both directions from an intermediate shaft 300 feet deep. Its total length is 6,600 feet and its sectional dimensions are 7-foot post, 5-foot sill, and 4-foot cap; its grade is three-fourths of an inch to a rod, and the water flume is 3 feet wide and 2 feet deep. It was completed after being pushed under contract in record time, at an average of 15 feet a day, with 3½-inch Ingersoll drills, at an estimated cost total of $200,000. This tunnel strikes the Anchor shaft at the 1,200-foot level and suffices to drain the property. The lower levels are very wet, especially at the faces, and the lowest levels are under water. In 1904 the water flume was entirely rebuilt

of heavy stuff, and 22-pound rails were laid preparatory to installing a power engine for hauling ore trains by compressed air.

The country rock adjoining this general zone on the west and northwest is made up largely of red shales cut by numerous strong and persistent fissures and has also been found to hold considerable water. After various unsuccessful efforts to overcome this obstacle, a drainage tunnel was started in June, 1889, from the mouth of Walker & Webster Gulch in a southwesterly direction, and was completed on August 17, 1890, for a distance of 4,590 feet. Its inside timber measurements are 7-foot post, 4-foot cap, and 4-foot sill. Its present length is considerably over a mile; and in addition to efficiently draining the ground opened by the several mines consolidated in the Kearns-Keith property and affording a deep work and exploration tunnel for future needs, it supplies water for domestic use in Park City and for use in the mill of the Silver King plant.

The Silver King mine, the other great property of this district, lies immediately northwest of the tract drained by the tunnel just described. It has been opened in rocks of the same formations as those penetrated by the wet mines, and yet, according to its operators, it has not been troubled by water in the least. It is probable that the water which the sedimentary rocks on this property would naturally contain drains off into deeper mine workings and canyons. This possibility is more apparent on reference to the profile section (fig. 16, p. 135) showing the relative depth of the deeper mine workings in the district.

The country rock bordering this central region marked by the deepest mining remains to a large extent undrained, however, as work on the properties which are now being opened in this ground is proving. The Silver King Consolidated Co., on reopening the Bogan shaft in the red shale in the ridge north of the Silver King mine, encountered an exceedingly heavy flow of water. During 1903 and 1904 a great outlay was made for enlarging the plant and installing more powerful pumping machinery, and the shaft was lowered a few hundred feet to the 800-foot level, where work had to be abandoned. In 1905 still more powerful pumps were put in so that work might be resumed. Again, in the J. I. C. property, on the divide between the Daly West and Daly-Judge on the north and Bonanza Flat on the south, and at considerable elevation, pumping has proved to be a most serious problem. In contrast with the large amount of water encountered in the outlying properties, the practical absence of water in the new workings, such as the Wabash, New York, Naildriver, and American Flag, in ground adjacent to the large mines, and thus within the drained region, is noteworthy.

The ventilation of the mines of Park City as a whole is remarkably good. Noxious gases are not encountered in development work. Through the numerous connections of the great mines with the workings of adjacent properties and with the surface, an excellent circulation of air is maintained. Indeed, in the drain tunnels and shafts, as well as in parts of the main mine workings, the normal movement of air is so strong as to extinguish a candle flame. The prevalent use of compressed air throughout the mines contributes greatly to the movement of the air, especially at faces outside of the general circulation. This circulation is further aided in certain properties, notably in the Ontario mines by a sucker operating on the surface through a system of air pipes, which extend throughout the mine to all accessible workings. In this manner the impure or vitiated air is withdrawn from the mine and the fresh heavier air descends to replace it. This machine is set up so that it may be reversed in case of emergency to act as a blower, and in both capacities it has proved highly satisfactory.

CONDITIONS OF THE MINERS.

The conditions of living in this district as compared with those in other western mining camps are good. Climate, sanitation, pay, relations with employers, and other essentials are here admirable. The elevation of 7,000 to 10,000 feet along the top of the Wasatch on the slope away from the desert insures cool, bracing air. The streams from the high divides and underground workings yield abundant supplies of water for domestic use, and the steep and well-watered slopes afford satisfactory removal of wastes. A pipe-water system for house and fire

service, a well-equipped plant for lighting buildings and thoroughfares with electricity, energetic police and fire departments, and wise and efficient city government contribute to make Park City an exceptional mining community. The relations existing between mine operators and employees have been mutually cordial and considerate. This happy condition is doubtless due in large measure to the fact that those who control the large properties have risen from the ranks, many of them having been miners themselves in this district. The good will prevailing results in the constant improvement of the miner's conditions of living and working by the operator and a return of honest labor and personal regard for the owner's interest by the miner.

The large mining companies have erected at the mines comfortable bunk houses equipped with modern conveniences for the unmarried men. Good meals are served to these roomers at large company boarding houses at moderate prices. This boarding and rooming with the company is not, however, required, and many of the men without families and practically all the married employees have neat and comfortable homes in Park City proper. All material necessities are obtained from large, well-stocked department stores—none of the mines conducting stores of their own—in which accounts may or may not, according to the wish of the miner, be run against his pay.

These excellent conditions combine to attract a high class of workmen and to hold them for long periods. The wages, though not quite as high as in some camps, are above the average and afford comfortable subsistence. The wage scale is slightly modified at some mines to meet special conditions but averages as follows: For an eight-hour day miners receive $3.50, trammers $3, cagers $3.25, and surface men $3.25. Strikes among the miners are practically unknown.

These conditions, though much superior to those which prevail in most mining camps, may be further improved to the common advantage of the operators and the miners. The well-equipped hospital recently erected under the auspices of the miners' union is a much needed benefit. The principal improvements that are still possible would aid the workman in developing mind and body, thus bettering his own condition and at the same time increasing his usefulness to his employer. A well-equipped gymnasium with a good reading room would afford an opportunity for rounding out both body and mind. Classes in gymnasium drill and various practical studies might be conducted by a trained librarian. Such work has been seen by the writer in successful operation at other mining settlements and there is every reason why it should be beneficial in Park City. The state of the camp is now so high that the principal room for improvement remaining lies along such advanced lines.

REDUCTION.

GENERAL CHARACTER OF THE ORES.

The ores of the Park City mines are of both smelting and milling grades. In the past many large bodies of first-class ore have afforded shipments which have brought the camp its reputation as a place of bonanzas. Recently, however, bonanza ores have begun to show the drain upon them and extensive bodies of low-grade ore have been opened, so that more and more attention has been given to concentration. At present (1904) approximately one-third of the entire output of the camp is smelting ore, and the rest is milling ore, the Silver King yielding shipping and milling ore in the proportion of about 7 to 6 and the Daly West 1 to 4, the Ontario yields milling ore altogether.

The Park City ores carry high contents of lead and silver with accessory gold and copper. The first-class ore is essentially sulphides of lead (galena), copper, and iron (tetrahedrite) with high accessory silver values. This combination together with carbonates and oxides constitutes the normal smelting ore.

The milling ores are made up of galena, pyrite, and zinc blende scattered through a quartz gangue. The silver lies in the pyrite and in the galena. Hence the problem in concentration is to save the galena and pyrite, together with any chalcopyrite and tetrahedrite which may be present, and to throw out silica and all the zinc blende in excess of the allowance. In practice the difficulty in effecting such separation is found in saving the silver that tends to escape

with the fines. The great and growing importance of these ores has led to much work by resourceful, experienced millmen. Through their persistent and intelligent researches the problems are being so well solved, in some cases by the special adaptation of ordinary apparatus and by invention of new machinery, that unusually high savings are now effected. In fact it is understood that the saving of silver in ores of this character accomplished at the Daly West mill is not equaled elsewhere. In view of these facts it seems desirable to describe the equipment, methods, and results of the more important milling plants in this district in some detail.

CONCENTRATION.

In a broad sense the milling of Park City ores falls into three periods characterized by different methods—the early experimental stage relying chiefly on mechanical means, the intermediate stage in which both chemical and physical methods were employed; and the third stage marked by the purely physical processes of modern wet concentration.

During the summer of 1874 the first mill (the Marsac) was built, equipped with 20 stamps and put into operation on ore from the Flagstaff mine. About the same time another 20-stamp mill, with pans, settlers, etc., was completed, with the expectation of starting on the ores of the McHenry mine. Early in the following year a third 20-stamp mill was completed, which in June went into operation on Ontario ore. In 1875 the McHenry mill was also running on Ontario ore and arrangements were being made by the Ontario Co. to lease and operate the Marsac mill. The early milling operations thus embrace building on a small scale and the use of simple devices for separation.

The intermediate stage was marked by enlargement of the leading mills and by refinement and development of processes of treatment. Thus on February 1, 1877, the capacity of the original Ontario mill was increased by doubling the number of stamps. As it was then regarded as the largest and best-equipped mill in the country, it merits a brief description.[1] The plant comprised two Blake rock crushers, one Lane & Bodley hydraulic lift, two rotary driers, eight Cochrane & Hendy self-feeders, forty 850-pound stamps of 8-inch drop, speed 94 drops a minute, double-discharge dry crushing batteries, twenty-four combination pans, twelve settlers, one agitator, two cleanup pans, one quicksilver elevator, four retorts, two melting furnaces, one battery of five 400-pound stamps with 7 to 7½-inch drop, speed 90 drops a minute, screen No. 20 for crushing salt, two Stetefeldt roasting furnaces with flue dust chambers, one Howell roasting furnace and dust chamber, one 250-horsepower engine, and four horizontal boilers.

The method of concentration was by dry crushing, chloridizing-roasting, and pan amalgamation. The ore after being weighed passed over grizzlies to crushers and thence to driers. After being dried and mixed with 15 to 18 per cent of dry crushed salt from Salt Lake this mixture was carried in wheelbarrows to the self-feeders of the battery, where it was crushed to pass stamp screens of brass wire No. 30 having 900 meshes to the square inch, and was next subjected to chloridizing-roasting over a special design of the Stetefeldt furnace. From the hoppers at the furnace the ore was dumped on the cooling floor, allowed to remain from 16 to 20 hours to cool, and then wet down. After that it was dumped into pans, 300 pounds of quicksilver being added to a charge of 2,800 pounds of pulp, and treated with live steam for 8 hours at temperatures ranging from 190° to 160° C. The pans were discharged into settlers which were filled with water, run 3½ hours, then slowly emptied. The quicksilver was separated from the amalgam by steaming in duck bags. The fineness of the bullion produced after melting in Dixon crucibles averaged 0.750, the impurity being mainly copper; the saving was stated to be 92.7 per cent of the silver, and the total cost of milling $15 a ton.

In 1880–1882 the other important mill, the Marsac, was remodeled and enlarged for custom work and fitted with dry kilns and water. Gradually a process was developed here which was largely chemical. It was essentially a lixiviation process and was named after its inventor, Russell. The Russell process, in addition to extracting the silver by normal lixiviation methods after chloridizing-roasting, sought to introduce new methods so as to produce the bullion free

[1] Rothwell, R. P. The cost of milling silver ores in Utah and Nevada: Trans. Am. Inst. Min. Eng., vol. 8, 1880, p. 551. Huntley, D. B., Tenth Census, vol. 13, p. 276.

from lead and to minimize and in some cases to abandon entirely the chloridizing-roasting. The process [1] consists in general of the following operations: (1) Matting the sulphides in an iron pot; (2) roasting the pulverized matte in a muffle furnace; (3) dissolving the roasted matte in dilute sulphuric acid; (4) crystallizing from the solution bluestone which is used in the mill for preparing Russell's extra solution; (5) washing the silver residue, pressing it into cakes, and melting the dry cakes to bars.

The essence of Mr. Russell's process was based on his discovery that "lead can be completely separated from a sodium hyposulphite solution as lead carbonate by sodium carbonate or purified soda-ash, without precipitating any copper or silver." [2] The plant comprised a matting furnace, a Brueckner pulverizer for pulverizing matte, a muffle furnace for roasting pulverized matte, a Roessler converter, two dissolving tanks, two filter tanks, six crystallizing vats, wash-water tanks, Koerting pump, two copper precipitating tanks, a cake press, and a drier for silver cakes.

It was claimed by the operators of the Russell process that after most critical comparative tests on ore by this process and by the amalgamation process, they found that the amalgamation process had the advantage in three points, namely, fineness of product in silver, fineness of product in gold, and cost of marketing silver, but that the Russell lixiviation process had the advantage in the following 16 points:

Coarseness of crushing.
Percentage of salt used.
Fuel used.
Capacity of roasting furnace.
Weight of charges.
Water used.
Power.
Temperatures.
Iron.
Chemicals used per ton.
Labor.
Extraction of silver.
Extraction of gold.
Baseness of product.
Cost of marketing gold.
Chemicals in use.

In short, it was claimed that the difference in favor of the Russell process amounted to about $3 a ton if the same number of tons were treated in each mill.

While these two processes, lixiviation and amalgamation, were being thoroughly tried out, the initial steps in the direction of modern wet concentration were being taken. "In a building near the Marsac mill and owned by that company four McKim concentrating machines were used successfully to concentrate both the tailings of the Ontario and the second tailings of the same mine after they had passed through the Marsac mill." [3] These pioneer machines originated at Park City and were patented February 15, 1876. After some experiments they were built in 1878 and ran successfully for two years, when the old reservoirs of tailings were exhausted. They consisted of a frame measuring 15 by 5 feet and inclosing an endless canvas belt which passed over rollers at either end, and they appear to have resembled roughly a Frue vanner. The tailings were fed into a common agitator from which they ran in a stream upon the belt. Small streams of water flowed over the belt from above; the heavier particles settled near the top and the lighter ones were washed into a trough, and final concentrates, middlings, and waste were thus separated. A concentration of 17 into 1 yielded a concentrate which assayed from $85 to $140; tailings which received further treatment averaged $13, and waste sands carried $5 to $6.

Subsequently the Crescent Co., after endeavoring to smelt its ores without success, remodeled the old Crescent mill in 1886 and refitted it with additional machinery, including seven Frue vanners, two Huntington rolls, two Cornish rolls, and two rock crushers and screens, which raised its capacity to 100 tons a day.

In 1889 the Union concentrator was erected in Empire Gulch and equipped to handle 100 tons a day by the general method of modern wet concentration. It started in July and first

[1] Stetefeldt, C. A., Russell's improved process for the lixiviation of silver ores: Trans. Am. Inst. Min. Eng., vol. 13, 1885, pp. 47–118. Daggett, Ellsworth, The Russell process in its practical applications: Trans. Am. Inst. Min. Eng., vol. 16, 1888, pp. 362–495. Daggett, Ellsworth, Amalgamation at the Ontario mill compared with the Russell process at the Marsac mill: Eng. and Min. Jour., Mar., 1891. Stetefeldt, C. A., The Marsac refinery, Park City, Utah: Trans. Am. Inst. Min. Eng., vol. 21, 1892–93, pp. 286–298.

[2] Stetefeldt, C. A., Trans. Am. Inst. Min. Eng., vol. 13, 1885, p. 47.

[3] Huntley, D. B., Tenth Census, vol. 13, p. 441.

ran on 10,000 tons of Woodside ore averaging $15 a ton. The Mayflower mill was built soon after in Woodside Canyon, and the Union mill, which had been running on various custom ores, was gradually given up to the treatment of Anchor ores.

The wet concentration process was so successful that it gradually supplanted the others, and during the nineties each of the great companies erected a large mill on its own property for the treatment of its own ores by this method. Each of these mills has been enlarged and remodeled more than once until the present plants have been developed, and in 1903 the Kearns-Keith, the latest mill in camp, was put up. The equipment and general process employed in these plants will be stated briefly and special features will be pointed out.

The Daly West mill is situated east of the Daly West shaft and is continuous with the shaft house. It was built in the middle nineties at a moderate cost and had a capacity of 50 tons a day. In 1900 it was remodeled and since then from time to time has been enlarged and rendered more and more efficient under F. W. Sherman as superintendent, until late in 1904 the quantity of ore treated daily reached 400 tons. The writer is indebted to Mr. Sherman for facts regarding the Daly West mill as well as for other valuable information on concentration. A general sketch of the operation of this mill is contained in an article by Mr. Sherman.[1]

In the highly perfected method of treatment which has been developed at this mill the leading principle is to avoid loss in sliming by preventing formation of slimes and by saving the metals by special means from those slimes which are unavoidable. In general, the treatment consists of crushing in stages, the removal of free particles of mineral after each crushing, so that the subsequent crushings will make less slimes, and the rejection of gangue particles in stages. This plant embraces the mill proper (No. 1), equipped with ore bins of 2,000 tons total capacity, one Gates gyratory crusher No. 4, one Richardson scale having a capacity of 1,000 pounds, two pairs of rolls measuring 14 by 36 inches, four cylindrical screens of 3, 4, 6, and 8 mesh, 5 double Hartz jigs, a dewaterizer, three 5-foot Huntington mills, seven Sherman fine-ore separating and distributing tanks, and eight Wilfley tables; also a tailings mill (No. 2), erected in 1904, fitted with six Sherman tanks, one Overstrom table, three Wilfley slime tables, twelve specially designed settling tanks, and a modified Wilfley slime table; and a tailings mill (No. 3), erected in 1906, which has five Sherman slime tables. The power is furnished by a 60-horsepower Corliss engine, 100-horsepower dynamo, and a complete machine shop and blacksmith shop have been erected for the plant.

The following description is substantially an abstract from the paper by Sherman already cited:

> In the process of concentration the ore is fed from the ore bins by a belt-driven eccentric plunger feeder on to a conveying and sorting belt 32 inches in width traveling at a speed of 40 feet a minute, which delivers its load of ore directly to a cup elevator when receiving fine ore, or first to the gyratory crusher when receiving coarse ore. By hand picking from this belt the first recovery of mineral and rejection of waste is made. The cup elevator delivers the ore to a set of scales, which weigh and register it automatically in 1,000-pound lots and deliver it into the bin just above the coarse rolls. Another eccentric plunger feeder delivers the ore to the rolls, water being introduced just before crushing to prevent dust. Between the coarse and fine rolls the fines are taken out by means of a revolving trommel. The entire product is reunited beneath the fine rolls and together classified for the jigs by a series of screens. The whole operation of delivering five classified products to the jigs and of reclassifying the tailings from No. 1 and No. 2 jigs after being recrushed is accomplished by the use of only six revolving screens and in a new manner, which simplifies the work of jigging. The location of the "return screen" is directly below the first screen of the series. It is a 2-mesh conical screen, and the first screen of the series is a 3-mesh. The oversize of the 3-mesh goes to the 2-mesh; the undersize of the conical 2-mesh goes to the No. 1 jig for treatment, and its oversize product is again returned to the fine rolls by a cup elevator.
>
> The tailings from No. 1 and No. 2 jigs are treated by a somewhat unusual method, in that they are returned by cup elevator to a third set of rolls on the same floor as the second set. After being recrushed to the undersize of a 4-mesh screen, they again join the regular jig product as it enters the third screen of the series, and are rejigged along with the original ore feed going to No. 3, No. 4, and No. 5 jigs. The material going to No. 5 jig is only the coarsest portion of the undersize product from the last trommel; the fine ore and slimes are taken off by means of a fine-ore separating and distributing tank and carried to a settling and classifying system.
>
> No jig rejection of tailings is made. Two compartment jigs remove the freed particles of mineral. From No. 1 and No. 2 jigs the greater part of the mineral is removed by side discharges, while No. 3, No. 4, and No. 5 make nothing

[1] Sherman, F. W., Wet concentration: Mines and Minerals, vol. 25, Dec., 1904, pp. 248–251.

but hutch concentrates. The tailings from No. 3, No. 4, and No. 5 jigs are elevated by cup elevator to an unwatering screen, the undersize of the screen along with the water going to the regrinding mills direct, while the oversize drops into storage bins to be delivered to the mills by plunger feeders. From the regrinding mills the product goes to a second fine-ore separating and distributing tank, whence the coarse goes to six concentrating tables. On these tables there are made a finished concentrate, a middling product, a tailing rejection, and a slime-water recovery. The last goes to the classifying tanks, the tailing rejection to the tailing launder; the middling product is sent by centrifugal pump to a third fine-ore separating and distributing tank, where again the coarser product is distributed to a second series of six concentrating tables, on which in turn is also made a finished concentrate, a middling, a poorer middling, a tailing rejection, and a slime-water recovery. The middling is again returned by pump and tank to the same series of tables, the poorer middlings to a tailing mill, and the balance of the products are treated in the same manner as from the first series of tables.

Special treatment has been devised for the fine ore and slimes and the water accompanying them, which include the products from the four fine-ore settling and distributing tanks. These are treated through a series of seven fine-ore settling and classifying tanks, each tank of which delivers a classified product to its respective concentrating table, on which is made a finished concentrate, a middling and poorer middling, a tailing rejection, and a slime-water recovery. These several separations are treated in identically the same manner as corresponding products from the second series of six tables.

After the entire water system is filled up, no fresh water is introduced except on the front of the concentrating tables. The water on the rolls, screens, jigs, and half the amount used on the concentrating tables is supplied by overflow from the last fine-ore classifying tank. Only 300 gallons of water are used in treating a ton of ore under ordinary circumstances. When economy is necessary, 150 gallons will suffice. The fineness of each of the grindings depends on the nature of the ore. Ores which yield their minerals easily are ground to the undersize of a 16-mesh screen, but the more refractory ores have to be ground to the undersize of a 40 or 60 mesh. Two hundred and five horsepower is sufficient to treat 500 tons of ore a day by this process. The expense of treatment in the tailings mill is about 12½ cents a ton. The total cost of treatment under ordinary circumstances, it is stated, can be held at 50 to 60 cents a ton.

In the mill proper the degree of concentration is 4 to 7 and averages 5 into 1; in the tailings mill it is 35 into 1. The milling ore runs from 4.5 to 5.5 per cent of lead and 12 to 14 ounces of silver; the concentrates 32 per cent of lead, 56 to 62 ounces of silver, and 15 per cent of zinc; and the tailings average 0.05 per cent of lead and 4 ounces of silver. Precise and exhaustive records show that the saving accomplished is 98 per cent of lead and 75 per cent of silver.

The Daly-Judge mill is located in Empire Gulch just below the mouth of the Anchor tunnel. It is practically a new mill, having been built and then greatly enlarged in 1902 and subsequently remodeled without having run long on ore. It has a capacity of 500 tons a day and is the largest in camp. As it was first laid on the general lines of the Daly West mill under the direction of F. W. Sherman, it does not differ in general plan and process from that mill as described above.

The Silver King plant is the most complete and the most expensive in the district and in equipment and efficiency is excelled at very few camps.[1] The plant comprises, in addition to the mill and the sampler building, a separate engine and boiler house, an aerial tram, and a loading station at Park City. Its 250-ton automatic sampler and the aerial tram were put in commission June 1, 1901.

The process of sampling is carried on as follows: All of the ore—that direct from the shaft as well as the concentrates elevated from the foot of the mill—is carried to the bins at the head of the sampler. These consist of an upper and a lower set, each set having a capacity of 600 tons. The ore then passes on a belt conveyor to a gyratory crusher and thence to five elevators. The first elevator handles the entire product, raising the ore to the third floor, where 80 per cent is discharged into a second elevator, and thence into the bins, and 20 per cent is cut out and dropped to a Cornish roll. This part after being rolled is sampled and 20 per cent again cut out. The remaining 80 per cent goes to the bins and the cut-out descends again to a Cornish roll. This operation is repeated, with the result that each successive rolling produces a finer product; that from the last rolling passes through a 200-mesh screen and is about the size of wheat grains. These final samples are steam dried. The slimes from the mill are dried to a degree just short of what would convert them into dust and are then sampled by hand. Power is furnished by a compound Corliss engine of 125 horsepower, and the operations of the sampler are normally carried on by six men, though even a smaller number can perform them. The aerial wire tram is described on page 24.

The concentration mill is built double throughout, so that either side may be operated independently. It has a capacity of about 200 tons a day, but at the time of visit was treating

[1] See a sketch of this property on p. 180.

about 105 tons in a 19-hour day. It has since been remodeled, and at the present time is accomplishing results which are very satisfactory to its owners. The method of treatment is the usual one followed in wet concentration, except in the treatment of the slimes, for which the filter press system has been adopted. Each side of the plant comprises a Blake crusher, 2 cylindrical screens, rolls, automatic sampler (cut giving sample for value and moisture), 4 trommels, 9 jigs, a dewaterizer, 2 Huntington mills, 10 Wilfley tables, 2 classifiers, 5 Frue vanners, and 4 Wilfley slime tables.

The method of recovery from the slimes, the feature of special interest in this mill, is by forcing them through a filter under high pressure from compressed air. The machinery required includes slime settlers, slime receivers, air receivers, air compressors, a slime press, slime cake cutter, belt conveyor, and Cummer drier. The slimes which carry sufficient mineral to warrant further treatment are first passed through a series of six V-shaped settling tanks. The settlings are then drawn off and elevated to a stock tank, whence they are released to charge two receivers of 2,500 gallons capacity. Thence the settlings are driven by compressed air into three filter presses, one of 1,400 pounds capacity, the others of 2,000 pounds capacity. After being subjected to high pressure the pressed slimes are dumped on a belt conveyor, transported to a chopping machine, thoroughly chopped, and then subjected to high heat. On emerging from the drier the product is taken by a screw conveyor to an elevator, thence to a high-line elevator, which transports it from the foot of the mill to the top floor of the sampler.

The power and light for the mill are generated by a 150-horsepower Corliss engine, except at night, when a 90-horsepower Corliss engine is used to generate current for the lighting. The superintendent of the mill reports that the saving now accomplished is 92 per cent of lead, 85 per cent of silver, and 75 per cent of gold; that the total cost of this concentration is $1.04 a ton; and that from the slimes, by the filter-press treatment, a saving of $6 to $8 a ton above all expenses is made. A considerably smaller portion of the total output from the Silver King mine is concentrated than of that from any other large mine in the district.

The mill that was erected at the Kearns-Keith property in 1903 is an exact duplicate of a single unit of the Silver King mill. The ore from this property, however, differs considerably from that of the Silver King, being largely of milling grade and high in zinc blende and iron. After some experimenting a concentrate was obtained that was considered fairly satisfactory.

The latest large mill built was the Ontario, in 1904, when both the walls and the interior of the old Ontario amalgamation mill were remodeled and a modern plant for wet concentration was installed. In removing the old tanks and excavating where they had stood it was discovered that during the operation of the amalgamation mill mercury had been leaking into the earth. Between $3,000 and $4,000 worth of mercury, it is said, was recovered from this ground.

The remodeled mill was started in February, 1904, with a small initial equipment, which was increased after some experimenting. At present writing the capacity of the mill is 150 to 200 tons a day, and the bins will hold 400 tons. The plant includes an electric hoist for ore in cars from the mouth of the work tunnel (600-foot level) to the head of the mill, about 175 feet, a 9 by 15 inch Blake crusher, Cornish rolls 40 by 16 inches, Davis rolls 36 by 16 inches, trommels, Hartz jigs, 5-foot Huntington mills, 13 Wilfley tables, and 3 Wilfley slimers.

The treatment is by the normal wet method. The degree of concentration at first was 7 into 1, but it has been gradually reduced until in May, 1905, it was 4.68 into 1. The entire output from the mine passes through the mill. The average assay value of the ore treated in 1904 was silver, 18 ounces; lead, 2.125 per cent; copper, 0.286 per cent; gold, 0.02125 ounce; zinc, 6 per cent; iron, 3.77 per cent. The average value of the concentrated product in 1904 was silver, 84.91 ounces; lead, 13.53 per cent; copper, 1.29 per cent; gold, 0.07 ounce; zinc, 16.53 per cent; iron, 12.35 per cent. The highest saving for any month was 93 per cent of lead and 73 per cent of silver, and the manager has stated that the saving can probably be made to average 90 per cent of lead and 70 per cent of silver.

Smaller mills have been built at other mines in accordance with their respective needs and are run intermittently according to the supplies of ore and water. The Comstock mill is well constructed and equipped and is reported to have a capacity of 120 tons. It is supplied with

water from the mine shaft, and its steam power is generated at the shaft plant. The equipment comprises a wet crusher, 3 cylindrical screens, 3 jigs, and 1 Huntington and 6 Wilfley tables. Good results are said to have been obtained here. A small mill is situated just above this plant at the California mine. Its outfit comprises the equipment of the old Sampson mill, with some additions and adaptations, and is understood to have given fair satisfaction in the treatment of the highly zinciferous ores from the California.

In Woodside Canyon just below the Silver King plant the old Mayflower mill has been renovated and is run for a part of each year on old dumps and tailings with good profit reported. In Empire Canyon several small temporary plants have been established from time to time for reworking the tailings from the Daly West and Daly-Judge mills. The one which remained longest was equipped with a Wilfley table, for which power was obtained by means of an overshot water wheel. It was currently reported that this plant paid, but when tonnage shipped and assay values of concentrate were checked against working expenses the balance did not appear to be favorable. Some hand-jigging of natural concentrates that was done in Silver Creek below the town and near the sampler does not appear to have proved successful. Tailings from Woodside Canyon are hauled to a plant in town where they are further concentrated and sold, it is reported, at a profit. The new tailings mill at the Daly West mine has caused lessees on creek tailings below to abandon further work, and the only slimes which are allowed to pass the King mill are those which the manager deems too low in grade to pay for treatment in the filter press.

TREATMENT OF ZINC ORES.

An important problem in handling the ores of this district is to separate and to save the zinc blende, and various attempts to solve it have been made. An entire plant was recently erected for this purpose, and at date of writing some recent experiments are reported to have been successful.

Considerable zinc blende occurs in the sulphide ores, more particularly in those from the deeper parts of the veins and from the western section of the district. Among the large producers the only mines that yield ore carrying much zinc are the Daly West and Daly-Judge. The average percentages of the main constituents in the concentrated ores of these mines, which consist almost entirely of sulphides, are as follows: Daly-Judge mine, lead, 8 to 10 per cent; zinc, 8 to 10 per cent; iron, 6 to 10 per cent. Daly West mine, lead, 4 to 6 per cent; zinc, 6 to 8 per cent; iron, 4 to 6 per cent. In 1904 the Ontario milling ore carried an average of 6 per cent zinc. The California and Comstock ores also carried much zinc.

The zinc blende, having a specific gravity of 3.9 to 4.1, usually occurs in a quartz gangue associated with pyrite (specific gravity 4.95 to 5.1), galena (specific gravity 7.4 to 7.6), and a small amount of chalcopyrite (specific gravity 4.1 to 4.3). The usual gravity methods of wet concentration suffice to separate the zinc from the galena. But clean separation from the chalcopyrite and the pyrite, of approximately the same specific gravity, can not be effected by these methods.

The particular characters of the respective ores also present special problems. Thus, although the zinc and iron of the Daly West ore carry sufficient silver to permit shipping these with the lead at a good profit, it is believed that it will pay to make separate concentration of the zinc and iron, and thus save both and obtain a clean zinc concentrate, besides additional silver. In the Daly-Judge ore, however, as neither the zinc nor the iron carries enough silver to yield a profit if shipped under a lead contract, the problem of saving the zinc consists in finding a way to first cut out the zinc and iron from the lead as cleanly as possible and then to separate these products into marketable concentrates. Various attempts have been made to accomplish these results.

In August, 1902, a plant was built below the town by the Park City Metals Co., a close corporation capitalized in Boston, to save the zinc from the Park City ores. For information regarding this mill the writer is indebted to Mr. Glazebrook, its former superintendent. It embraced the old Peck concentrator building, roaster, separator, etc., and important new

machinery. Experiments on ore from the Daly-Judge mine had previously been made at Leadville, which it was believed had proved the possibility of making satisfactory separation of the zinc, and these were continued with most gratifying results at the new plant. The equipment comprised one cylindrical furnace, a Howell and Hoyt roaster, a Hooe conveyor and magnetic separator, and six Wilfley tables. This separator, which was specially designed in the course of the experiments here, consisted of a Wilfley table inclined at an angle of 15°, with two electromagnets suspended above a belt which extended immediately over the table. The method of treatment consisted in feeding the zinc middlings to the separator, where the magnets attracted the magnetic portion upward to the surface of the belt, the weaker upper magnet taking the iron and the stronger lower magnet drawing the fused magnetized zinc, lead, and silver. By the movement of the belt these suspended or attracted portions were carried beyond the magnetic field and on being released dropped into receivers—the iron affording a commercial product, but the fused zinc middling, carrying silver, lead, zinc and silica, requiring further separation. This middling was then passed over Wilfley tables, where the zinc, lead, and silica were separated, and a special device made it possible to secure an unusually sharp divison and clean product.

Over 1,000 tons were successfully treated by this process, and the product was shipped. It is stated that one lot of 35 tons ran 55 per cent zinc, that the average was about 52 per cent, and that the product rarely fell to 48 per cent, and that in the ultimate rejection the tailings loss was not over 5 per cent of zinc. At this point in the progress of the enterprise the plant burned to the ground in May, 1903, and the company being unable to obtain a renewal of its contract for middlings did not rebuild. The results attained were accepted as proving the commercial success of the treatment. Not content with this, the company had just set up for trial at the time of the fire machinery designed for an additional refinement of the process. This consisted in crushing the fused sinter gathered by the stronger magnet and returning the zinc and lead thus released for retreatment in the separator. It would doubtless have materially increased the saving of zinc.

The recent rise in the market prices of metals, together with the decrease in the amount of crude ore uncovered and the relative increase of ores carrying much zinc, has tended to further stimulate endeavors to produce from the zinc-bearing ores a marketable zinc concentrate. Thus in southern Utah, at the Horn silver mine, much attention is being given to the treatment of low-grade zinc ore, and in Salt Lake Valley the Western Metals Co. has erected a plant for the special treatment of custom zinc ores. At Park City F. W. Sherman, superintendent of the Daly West mill and formerly of the Daly-Judge mill, has conducted experiments on the ores of these two properties with a view to obtaining a marketable zinc product. The method which was thoroughly tested on 20-ton lots, and the results of the processs, are presented in the following concise statement, which was kindly prepared by Mr. Sherman by special request:

> The ore needs first to be crushed to the undersize of a 2-mesh screen, then treated over jigs. By this operation there is made but one finished product, and that is a high-grade lead concentrate; all the tailings from the jigs should be reground to the undersize of a 10 or 12 mesh screen, then reconcentrated over tables. Tables of the Wilfley type are entirely suitable for this operation. On these tables there should be made a high-grade lead concentrate and a zinc-iron concentrate; the lead concentrate can be made virtually free from silica, but will carry iron and zinc, each ranging from about 6 to 10 per cent. By cutting out a middling between the lead and the zinc-iron concentrate it is possible to make a lead product carrying fully 50 per cent and a zinc-iron concentrate carrying not more than 2½ per cent of lead, though the zinc-iron concentrate will be very siliceous, carrying fully 20 per cent of insoluble matter.
>
> The next question is how to handle the zinc-iron concentrate so that the lead, zinc, and iron will be separated into distinct products and the greater part of the silica removed. While the three metals are not chemically combined, yet their relations are so intimate that it is found necessary to regrind this combined product to the undersize of an 80-mesh screen before a further satisfactory separation can be made, making five classifications of this reground product, and then to treat each class over a separate concentrating table. On each of these tables there should be made a lead-iron concentrate, a lead-iron-zinc middling, a zinc concentrate, and a tailing rejection.
>
> The lead-iron concentrate needs still another treatment over tables by which these two minerals are separated and a high lead and a high-grade iron concentrate are made. By such a treatment a concentrate can be produced that will carry fully 40 per cent of lead; also, an iron product carrying but a small percentage of either lead or zinc, with the iron many points in excess of silica. Much silver will be recovered in this way along with iron that has of itself a commercial value, and which takes a much less treatment charge than does a lead concentrate.

The zinc concentrate, by a partial analysis, shows about the following composition: Zinc, 40 per cent; iron, 12 per cent; lead, 1 per cent; silica, 2 per cent.

The remaining question is how to raise this zinc to a higher grade without too great a loss. At present two processes are attracting much attention, and it is still questionable which can show the greater advantage in further separation of this class of material: One is known as the electrostatic method of separating zinc and iron, and the other as the magnetic method. In the electrostatic method the ore is simply dried and then delivered to a machine that effects a separation by repelling the iron from the zinc by means of static electricity. The great disadvantage of this process in dealing with such a product is the fact that it does not work successfully on a concentrate that is the undersize of 150-mesh screen. W. G. Swartz, of Denver, made a test upon a sample of this ore over a Blake-Mosier electrostatic machine and returned the following results:

Zinc concentrate: Zinc, 55 per cent; iron, 2 per cent; lead, 0.5 per cent; silica, 3 per cent.

Iron concentrate: Zinc, 9 per cent; iron, 37 per cent; lead, 4.2 per cent; silica, 4 per cent.

In the original sample there were 9 ounces of silver; in the zinc concentrate there were 3.6 ounces, and in the iron concentrate 21.8 ounces.

The Union Iron Works Co., of Springfield, Mo., which manufactures the Cleveland-Knowles magnetic separator, tested the same ore over its machine with the following results:

Zinc concentrate: Zinc, 56 per cent; iron, 1.7 per cent; lead, 1 per cent; silica, 3 per cent.

Iron concentrate: Zinc, 13.4 per cent; iron, 33 per cent; lead, 3.5 per cent; silica, 4 per cent.

The silver contents were approximately the same.

In this last operation it is necessary to give the ore a partial roast, thus changing the pyrites to magnetic iron. This roast presents the only real problem in this method of treatment, which is to remove the right amount of sulphur without fusing some of the concentrate, for this would again unite the particles of zinc and iron and thus make a middling product that is nearly worthless.

Thus each process has its disadvantages and not until such time as there are plants in operation treating this product continuously by these respective methods will it be proved which of the two offers the greater advantages. There is no question in the mind of the writer but that either can be made a commercial success, although to what degree is still doubtful.

The results of the operation of the Park City zinc plant and the tests made by Mr. Sherman show that the low grade zinc-bearing ore of Park City can be concentrated into a marketable product. The final decision as to which is the best method and the determination of the proper amount of roasting to render the zinc ore magnetic without fusing it are merely questions of time, and not neeessarily of a long time, so that the outlook for the increase in the value of Park City ores and output through the saving of another metal, zinc, is decidedly encouraging.

Since the preparation of this statement the Grasselli Chemical Co. has equipped a dry concentrating mill at Park City in which it has successfully treated a large product of zinc middlings from the Daly-Judge mine. In 1909 the Daly West began saving zinc, making an addition to its mill for that purpose.

SAMPLING AND SMELTING.

The concentrates and crude ores from all the properties in the district are shipped for reduction to a custom smelter at Murray 8 miles south of Salt Lake City. The ores from the Silver King mine are sampled at the mine (see p. 180) and thence go directly to the smelter. The ores from all the other properties in the camp are sampled at the Park City (Mackintosh) sampler, situated on the northern boundary of Park City, and are then shipped to the smelter.

The Park City sampler [1] was recently constructed to replace old works which had long been in operation. Two chief ends are aimed at in the treatment, namely to keep the ore as coarse as possible suitable for handling by smelters and to make the process as automatic as possible in order to reduce costs and charges to a minimum. The plant comprises a 24-inch belt conveyor, a No. 5 Gates crusher, five Vezin samplers making cuts of one-fifth, five sets of rolls measuring from 34 by 14 inches to 9 by 4 inches, a fine sample grinder, two Scotch marine boilers of 145 horsepower, with automatic stokers, a Corliss engine, and self-registering car scales. The capacity for which the sampler is designed is 500 tons daily. In the process of sampling the ore brought to the works in railroad cars is conveyed by a 24-inch belt to a No. 5 Gates crusher; thence it is elevated and delivered to a Vezin sampler, which cuts out one fifth to be retained in the sampling system; four-fifths are rejected and elevated to the shipping bin. The sample cut passes to a set of 36 by 14 inch rolls, which reduce the ore to about 1 inch. It is then elevated to a second Vezin

[1] This sketch of the Park City sampler is based on data presented in a paper by A. W. Warwick entitled "Notes on sampling," published by the Industrial Printing & Publishing Co., Denver. 1903, and kindly loaned to the writer by Mr. F. W. Hayt, the superintendent of the sampler.

sampler, which again cuts out one-fifth and rejects four-fifths. The sample cut, which is now one twenty-fifth of the whole, goes to a second set of rolls 30 by 10 inches, and thence to a third sampler, which again cuts out one-fifth, making the sample one one-hundred-and-twenty-fifth of the whole. This sample is crushed by a set of 24 by 8 inch rolls and then passes to a fourth sampler, one-fifth being cut out, which thus constitutes one six-hundred-and-twenty-fifth of the whole, the rejected ore as before going to the shipping bin. The sample cut is sent to a set of 9 by 4 inch rolls and crushed again to about one-tenth inch, and then goes to the fifth and last sampler which cuts out one-fifth, or one three-thousand one-hundred-and-twenty-fifth of the whole amount of ore sampled. The rejected ore goes to the shipping bin and the sample then passes to a fine sample grinder which reduces the ore to a 50-mesh screen and it is finally cut down by the ordinary methods for the assayer.

The custom smelter at Murray at which all of the Park City ores are reduced is an extensive, modern, and highly efficient plant. It comprises three divisions, the crushing and roasting department, the smelting department, and the power department. The roasting department includes a crushing mill and two furnace houses, one for Brueckner furnaces and the other for reverberatories. The smelting department comprises a steel furnace house inclosing eight blast furnaces 48 by 160 inches at the tuyers. The dust flue connects with large main flues and leads to a circular brick chimney 20 feet in diameter and 225 feet high. The power department comprises eight fire-box boilers with automatic stokers, two cross compound Allis-Chalmers (Dixon) blowing engines, two direct connected electricity generators and a machine shop. In addition to these departments are sampling and flue-dust briquetting mills. The equipment throughout has been designed to economize labor, heat, and transportation. In 1902 this plant and the Germania were producing 1,400 tons daily.[1]

The rates, which are not usually published, are made with each company according to the character of its ores and usually for long periods. In 1902–3 the rate on Daly West concentrates was $3.50 per 100 pounds for the lead contents.[2]

From time to time large shippers have seriously considered the erection of private smelting plants, but there has been no public discussion of this subject recently, so that doubtless rates are now satisfactorily adjusted.

PRODUCTION.

Metal contents of the production of Park City mines.

Year.	Gold.	Silver.	Lead, unrefined.	Copper, refined.	Zinc.
	Ounces.	*Ounces.*	*Pounds.*	*Pounds.*	*Pounds.*
1877		1,310,145			
1878		1,112,030			
1879		1,041,771			
1880					
1881	34	1,931,089			
1882					
1883	848	2,011,691			
1884					
1885	2,222	3,126,890			
1886	2,285	2,881,436			
1887	1,959	3,159,453			
1888	2,561	3,398,126			
1889	4,171	3,800,266			
1890	3,055	3,120,063			
1891	3,450	3,865,510			
1892	4,770	4,078,238			
1893	2,875	2,709,672			
1894	4,451	2,802,289			
1895	4,133	3,204,004			
1896	4,377	3,134,820			
1897	5,200	2,737,268			
1898	6,439	2,215,496	32,233,553	54,609	
1899	8,803	3,152,329	41,884,755	805,347	
1900	9,093	3,931,205	46,982,647	703,369	
1901	13,731	7,060,623	60,232,236	2,477,080	
1902	15,083	7,990,200	69,833,456	2,869,448	
1903	15,317	7,109,209	78,243,720	3,297,101	
1904	13,643	5,814,386	64,312,559	2,118,452	
1905	14,807	3,998,165	45,280,817	1,254,153	1,972,327
1906	11,884.67	3,755,339	46,511,176	1,194,216	3,518,139
1907	8,413.52	2,794,552	36,234,757	945,722	258,784
1908	5,083.34	2,463,735	34,051,699	541,061	1,405,652
1909	4,814.18	2,825,385	46,350,390	1,655,749	6,737,237
Total	173,502.71	102,535,385	602,151,765	17,916,307	13,892,139

[1] This general statement is taken from Mineral Industry, 1901, pp. 405, 406; 1902, pp. 411, 412.

[2] Ann. Rept. Daly West Mining Co. for 1902, p. 12.

The figures in this table for the years 1877 to 1901 have been compiled from reports of the Director of the Mint, Mineral Industry, and reports of the individual mines; those for the years 1902 to 1909, inclusive, have been compiled from reports furnished this bureau by each producing property in the district. The compilations for this later period are based on data furnished by V. C. Heikes, in charge of the Salt Lake City office of the United States Geological Survey, to whom the writer desires to express his cordial thanks for this as well as for continued kindly cooperation during the examination. Omissions indicate that data were not obtained. The mines operating in the early years—for example, the Ontario and Daly—contain such small quantities of lead that it was entirely neglected in the ore sales. Copper has been found to increase in depth and hence in the early history of the camp was not found. With these exceptions, the table shows the increased production of Park City mines from 1877 to 1903. A changing ratio of gold to silver and several fluctuations may be noted during that period as well as in the years that have followed. The first great break in the production of silver occurs, of course, in 1893 and was caused by the great fall in the metal market, as described above. From this time not only did the production of silver increase but also the ratio of gold to silver. In 1896, for the same reason as in 1893, a second break occurred in the production of silver, but in 1901 the output of the white metal almost doubled that of the preceding year and in the following year it rose still higher to its maximum point. During 1904 the production of the camp, including all metals, was 250,047 tons, which at current prices was estimated to be worth $6,335,865; that for 1909 was 143,422 tons, valued at $3,174,564.

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GENERAL GEOLOGY OF THE MIDDLE WASATCH RANGE.[1]

TOPOGRAPHY.

The Wasatch Mountains are a lofty rugged range trending north and south between the Great Basin on the west and the mountainous plateau regions on the east. From a ragged serrate crest of sharp ledgy peaks 10,000 to 11,000 feet high, the western side falls off abruptly 5,000 to 6,000 feet by a wall-like front to the desert below, but the eastern slope, in marked contrast, gives way gradually to plateaus and high-lying meadows. This unsymmetrical range may hence be compared to a mammoth step several thousand feet in height from the Great Basin on the west to the highlands, which extend from its summit eastward. These slopes are interrupted by deep, narrow, rock-walled canyons through which the drainage from the uplands and parks escapes westward to the desert. The portions of the western wall which lie between these canyons show a type of dissection marked by ravines that rise from the level of the desert with steep sides and bottoms and fork repeatedly upstream. Both the larger and smaller features of the topography—its rugged precipitous slopes, deep, narrow canyons with ungraded bottoms, and ungraded side cataracts—indicate the youth of this range.

STRATIGRAPHY.

The rocks which form the range are sedimentary, metamorphic, and igneous. The stratigraphic section includes great thicknesses of limestones, sandstones, and shales which range in age from Lower Cambrian to Tertiary. These were carefully described and classified by the geologists of the Fortieth Parallel Survey, and King has given the following general section of Paleozoic rocks for the Wasatch Range.[2] At the base are Cambrian slates 800 feet thick, followed by the Cambrian quartzite 12,000 feet thick and by Cambrian shales from 75 to 600 feet thick. The Ute limestone rests on the Cambrian shales and is a dark blue compact, fine-grained rock assigned to the Silurian. Next in the series is the Ogden quarzite, regarded by him as of Devonian age, generally thick, in many places saccharoidal, measuring 1,000 to 1,500 feet. The succeeding formation he called the Wasatch limestone and described as consisting of 7,000 feet of blue and gray rocks interstratified in the upper part with a few, persistent, light-colored siliceous beds and quartzites. It is stated that Coal Measure fossils are numerous down to a horizon 1,600 feet from the base, where occur sub-Carboniferous (Mississippian) types, these being preceded by a fauna of Waverly aspect and that by an assemblage of Devonian types.

[1] This sketch is based on writings by Clarence King and S. F. Emmons (U. S. Geol. Expl. 40th Par., vols. 1 and 2) and C. D. Walcott (Second contribution to the studies of the Cambrian faunas of North America: Bull. U. S. Geol. Survey No. 30, 1886; The North American continent during Cambrian time: Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, pp. 523–568) and on the observations and notes of the writer made in this region during the field seasons of 1900 to 1904, inclusive. The paleontologic portions were revised by G. H. Girty in January, 1912.

[2] King, Clarence, U. S. Geol. Expl. 40th Par., vol. 1, 1878, pp. 155–156, 248, 535–536; also Emmons, S. F., idem, vol. 2, 1877, p. 342.

The so-called Wasatch limestone is followed by the Weber quartzite, a heavy bed of quartzitic strata containing at both ends unimportant intercalations of limestone. The thickness is 5,000 to 6,000 feet. The next formation in order is made up of limestones interspersed with siliceous beds, the whole attaining a thickness of 1,700 to 2,100 feet. It contains well-defined Coal Measure fossils and is spoken of as the Upper Coal Measure limestone. Above this come in 650 feet of beds assigned to the "Permo-Carboniferous," composed partly of calcareous, partly of argillaceous, and partly of arenaceous materials.

Although in a general way this description, which has been shortened in the summary, affords an adequate notion of the Paleozoic section of the Wasatch Range, and although it was an important addition to the knowledge of the time, subsequent investigations have made noteworthy changes as well as additions. To only a portion of these will it be pertinent to call attention, as only the higher members of the section occur in the Park City district.[1]

Devonian fossils have been found only in the northern part of the Wasatch Range and the formation in which they occur has been withdrawn from the Wasatch "limestone" and correlated with the Jefferson limestone. In the Weber Canyon section the "Wasatch limestone" answers to King's description in so far as the lithology is concerned, but the upper portion contains a fauna not of Pennsylvanian but of Mississippian age. Paleontologic evidence indicates that it would be desirable to divide the Mississippian portion of the "Wasatch limestone" into two formations, the lower one containing a lower Mississippian fauna and correlating with the Madison limestone, the upper containing an upper Mississippian fauna. Aside from the incongruity of its original content, it is impossible to retain "Wasatch" for any one of these subdivisions, as the name was preoccupied for another series of sediments.

In the Weber Canyon section the "Wasatch limestone" is succeeded by a group of red sandstones and shales having a thickness of 500 to 2,000 feet, which has been named by Weeks and by Blackwelder the Morgan formation.[2] The fossils, especially those from some impure calcareous beds near the base, show the geologic age to be Pennsylvanian. This series of strata was mentioned by Emmons [3] and included by him in the Weber quartzite, but it is evidently not noted in the general description given by King, and, indeed, it may be of only local development, at least in so far as the color, which is a striking feature, is concerned. Of the remainder of the formation in Weber Canyon the lower part contains a considerable amount of calcareous material in the form of calcareous sandstones and sandy limestones, whereas the upper part consists chiefly of massive quartzite. Both portions have furnished fossils of Pennsylvanian age.

Perhaps no portion of the section has suffered more changes from recent revision than that which King included in the "Upper Coal Measure limestone" and the "Permo-Carboniferous." This series of sediments, as it occurs in the Park City district, has been subdivided into three formations, the Park City, Woodside, and Thaynes, to be described later in this report. The exact equivalents of these formations in the "Upper Coal Measure limestone" and the "Permo-Carboniferous" are hard to determine, but from the great thickness assigned to the former and the small thickness assigned to the latter it seems probable that the "Upper Coal Measure limestone" comprises not only the Park City formation but the Woodside and the lower part (200 feet or more) of the Thaynes formation. The Ankareh shale and the overlying Nugget sandstone appear to compose King's Triassic. Furthermore, recent accessions of paleontologic knowledge indicate that the Park City formation should be considered of Permian age,[4] while the Thaynes [5] and probably the Woodside and the Ankareh are the typical Lower Triassic of

[1] See, however, Walcott, C. D., Second contribution to the studies on the Cambrian faunas of North America: Bull. U. S. Geol. Survey No. 30, 1886, pp. 38–39.

[2] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Bull. Geol. Soc. America, vol. 21, 1910, p. 529.

[3] U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 377.

[4] The Park City formation contains the *Spiriferina pulchra* fauna, which includes, besides that species, *Productus subhorridus*, *Productus multistriatus*, *Productus nevadensis*, abundant Bryozoa belonging to the Fenestellidæ and Batostomellidæ, and many other forms.

[5] The Thaynes appears to represent the Meekoceras zone of southeastern Idaho, the typical American Lower Triassic. The Woodside fauna (as found in Idaho), though lacking ammonitic types, is closely allied to that of the Thaynes and widely different from the underlying Park City fauna. The Ankareh also seems to furnish the same general type of fauna as the Thaynes and no satisfactory evidence has yet been found which shows that that formation likewise should not be assigned to the Lower Triassic. There has been some division of authority as to the Triassic age of the Meekoceras beds of India, but the preponderance of evidence seems to assign them to the Triassic. If this is correct, and if the Meekoceras types were contemporaneous in both hemispheres, there can be no doubt that the Thaynes formation at least belongs in the Triassic.

North America. The Nugget sandstone is of either Jurassic or Triassic age. The correlation of these formations is more fully discussed under the description of the Thaynes formation (pp. 56–58).

The metamorphic rocks include the early regionally metamorphosed sediments and the locally altered or contact-metamorphosed rocks. Underlying the Cambrian in the Wasatch is a great metamorphic series made up of (1) a "granitoid series," (2) a "gneissic series," in places decidedly granitoid, and "hornblendic schists" 12,000 to 14,000 feet in thickness, and (3) mica schists, argillites, slates, and quartzite.[1] Beyond the fact that these great metamorphic series are pre-Cambrian, their age is not proved, though they are known to be the oldest rocks in the Wasatch.

The igneous rocks include several large granitic and porphyritic intrusives and extensive flows. The ages and relationships of these masses have not yet been completely established. They are strikingly alike in general chemical composition, yet sufficiently unlike in structure and occurrence to constitute distinct rock species. In the central Wasatch they reach their fullest development in a series of enormous laccolithic bodies which are geologically separate, petrographically distinct, and chronologically different in an extensive plexus of dikes and in vast sheets of breccia and acicular lava. The youngest intrusives in this area are at least as late as Triassic and the extrusives overlie sediments of late Tertiary age.

STRUCTURE.

Structurally the Wasatch Range is a composite orographic unit. In the largest conception it is a linear north-south anticlinal range truncated on the west and probably on the south by great faults. This major structure is made up of four parts—(1) the Logan syncline, pitching north; (2) the eastern limb of an anticline now constituting the western rim of a Tertiary basin; (3) in the middle part a narrow east-west syncline and an east-west anticlinal dome; (4) on the south the eastern limb of a north-south syncline, probably truncated south of Mount Nebo by a great northeast-southwest fault, with the downthrow on the southeast. These larger structures are exceedingly complicated by intricate faulting.

DESCRIPTIVE GEOLOGY OF THE PARK CITY DISTRICT.

PRINCIPAL FEATURES.

The greatest geologic activity in the Wasatch Mountains took place in the middle portion at its junction with the great east-west Uinta Range. Within this area the most diverse formations are found on a prominent spur which extends eastward from the main divide. Extensive and irregular intrusion, widespread extrusion, thorough contact metamorphism, persistent and recurrent faulting, and glaciation have produced in a comparatively small area highly varied and complex results. At the heart of the area, in the focus of these contending factors, have been formed the most extensive and richest ore bodies in the range. This area is known as the Park City district.

The general anticlinal structure of the Paleozoic and Mesozoic beds which characterizes the Wasatch as a whole is interrupted in this central portion by a transverse (east-west) anticline or dome. Sediments ranging from Cambrian to Tertiary here dip quaquaversally from a series of laccolithic masses. These masses include, from west to east, the porphyritic granite of Lone Peak and Little Cottonwood Canyon, the granodiorite at the head of Little Cottonwood Canyon in the vicinity of Alta, the coarse and fine grained dioritic masses at the heads of Big and Little Cottonwood canyons, and the northeast extensions in the form of dikes. It is noteworthy that these intrusions have taken place along the line of the Uinta axis extended westward. The doming by these masses athwart the general course of the Wasatch naturally raises a query as to similar action in the formation of the Uintas. This transverse Wasatch dome and the Uinta dome are separated topographically though not structurally by a north-south trough.

[1] King, Clarence, U. S. Geol. Expl. 40th Par., vol. 1, 1878, pp. 100–101.

Into this, and thus blanketing the surface connection of these structures, have flowed extensive and thick masses of andesite.

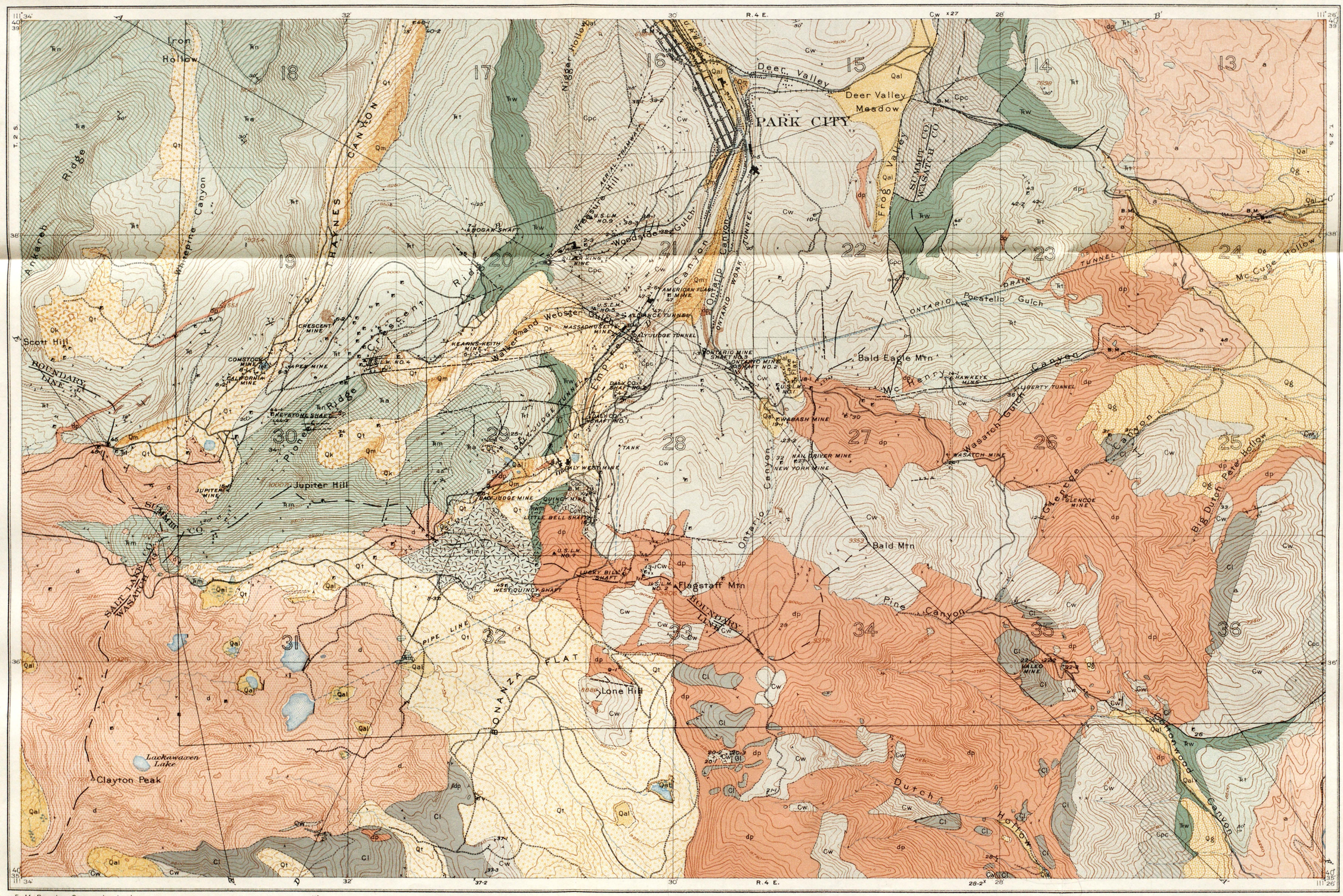
The portion of this region known as the Park City district is traversed diagonally by this axis. Here the sediments include beds ranging in age from lower Carboniferous to Triassic. They have been cut, deformed, and altered by a series of intrusives including the highest of the laccolithic masses, the diorite of Clayton Peak (Pl. IV, B), and the upward cutting stocklike and dikelike masses which extend northeastward diagonally across the area to the andesite flows which cover the sediments at the northeast. These sediments rim around the intrusives and dip off from them to the northwest, north, northeast, east, and southeast. (See Pl. II.) The area thus embraces the northeast end of the great composite laccolith of the middle Wasatch. The main divide of the range passes through the southwest corner of the district, and there in Clayton Peak the highest elevation in the area, 10,728 feet, is attained. From this peak the divide of the prominent eastern spur extends eastward 4 or 5 miles and there gives way to the general easterly slope, descending to interior high-lying valleys. It thus separates the district into three natural topographic divisions—the north and northwestern slopes, the easterly slope, and the southern slope. This topographic division accords with rock and structural divisions. The northern and northwestern area comprises a sequence of six sedimentary formations alternately siliceous and calcareous, ranging from Pennsylvanian to Triassic, and everywhere dipping to the northwest at a moderate angle. The prevailing deformation in this portion is faulting. The eastern slope shows the same formations, generally dipping eastward and partly buried on the northeast by an extrusive mass; these formations are intruded by large irregular dikes and stocklike masses and extensively faulted. The southern part embraces the great laccolithic stock of diorite in Clayton Peak on the southwest, dikes and stocks of andesite porphyry cutting up into the sedimentary formation above them, and a great east-west zone of contact-metamorphosed sediments. It is these metamorphosed and hardened rocks which stand up as the backbone of the region, and on their northern slopes are found all the great bonanza ore bodies of the camp.

The higher slopes, including the chief peaks and the valleys which radiate from them, bear evidence of local glaciation. The steep-walled amphitheaters or cirques which characterize the heads of these valleys uniformly inclose extensive glacial deposits in the form of kames. Below these cirques the valleys exhibit characteristic U-shaped profiles, ground and lateral moraines bowlder trains, perched erratics, striation, and scouring (Pls. VIII, p. 60; IX, p. 61).

SEDIMENTARY ROCKS.

DIVISIONS.

The sedimentary rocks of the Park City district are separable into six divisions. The lowest division comprises quartzites and limestones, each mapped separately. The quartzites are unfossiliferous but undoubtedly represent the Weber quartzite (of Pennsylvanian age), the type locality of which is Weber Canyon, to the northwest. Some of the limestones, however, are of Pennsylvanian age, and others have yielded lower Mississippian (Madison) fossils. All these limestones, whether of Pennsylvanian, Mississippian, or unknown age, are mapped together. Overlying the quartzite is the Park City formation, consisting of limestone and sandstone. The Park City formation has not furnished very abundant or well-preserved fossils, but the faunas obtained from it in Weber Canyon, at Salt Lake City, and at other localities in Utah, Idaho, and Wyoming are very characteristic and have provisionally been referred to the Permian. Next above is the Woodside shale. This formation is unfossiliferous in the Park City district, but in Idaho it has yielded a fauna which is quite different from that of the Park City formation and closely related to that of the overlying Thaynes formation. The Thaynes has been recognized in Idaho and Wyoming and includes the well-known Meekoceras zone, the typical lower Triassic of North America. These characteristic cephalopods have not yet been definitely recognized in the Thaynes formation in this district, but Meekoceras types have been found at the same horizon in Weber Canyon and at Salt Lake City. The next formation is the Ankareh



LEGEND

SEDIMENTARY ROCKS

Recent

- Qal — Alluvium
- Qg — Gravels (*Mixed deposits mainly on lower eastern slopes*)

Pleistocene

- Qm — Moraines
- Qt — Till
- Qk — Kames

QUATERNARY

- Rn — Nugget sandstone (*Coarse, pebbly white sandstone containing petrified wood.*)
- Ra — Ankareh shale (*Chiefly red shale, ripple marked and mud cracked, including thin beds of white sandstone and gray limestone*)
- Rt / Rtm — Thaynes formation (*Comprises limestones, calcareous sandstones, and shales; more calcareous upper portion separated from more sandy lower by "mid-red" shales. Abundant fossils*)
  - Rtm, *marble in contact-metamorphic zone*
- Rw / Rwm — Woodside shale (*Uniformly fine-grained dark-red shales*)
  - Rwm, *argillite in contact-metamorphic zone*
- Rm — Metamorphic sediments (*Includes limestone, marble, sandstone, argillites, etc. Age unknown, probably Triassic*)

JURASSIC OR TRIASSIC

TRIASSIC

Permian?

- Cpc / Cpcm — Park City formation (*Mainly pure, blue, cherty, and gray limestones; minor quantities of shale and sandstone*)
  - Cpm, *marble in contact metamorphic zone*

Pennsylvanian

- Cw — Weber quartzite (*Massive-bedded light-gray quartzite with few intercalated limestone beds*)
- Cl — Undifferentiated limestones (*Includes intercalated members in Weber quartzite and isolated blocks in igneous rocks*)

CARBONIFEROUS

IGNEOUS ROCKS

POST-CARBONIFEROUS

- a — Andesite (*Great series of extensive lava flows with sediments, coal, and water-worn gravels, interbedded locally*)
- dp — Quartz diorite porphyry (*Irregular stocks and dikes*)
- d — Quartz diorite (*Extensive stock*)

SYMBOLS

- Known formation boundary
- Probable formation boundary
- Dip and strike of strata
- Known fault
- Probable fault
- Dip and strike of fault plane
- Downthrown side of fault
- Shaft
- Tunnel
- Prospect
- Mine dump

E. M. Douglas, Geographer in charge.
Triangulation by Pearson Chapman.
Topography by Pearson Chapman and J. F. McBeth.
Surveyed in 1901.

Geology by J. M. Boutwell, J. D. Irving, and L. H. Woolsey.
Surveyed in 1902-1904.

GEOLOGIC MAP OF THE PARK CITY DISTRICT, UTAH

Scale 1/25000

1 Mile

1 Kilometer

Contour interval 50 feet.

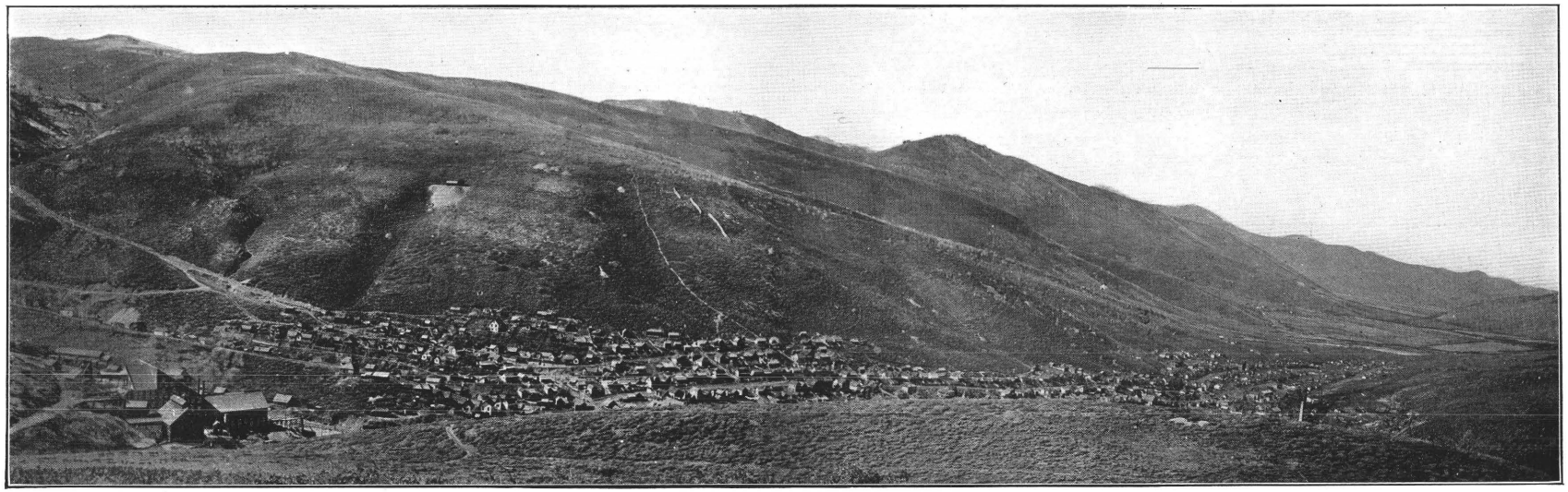
Datum is mean sea level.

(The elevations on this map were later found to be 11 feet too high)

1912

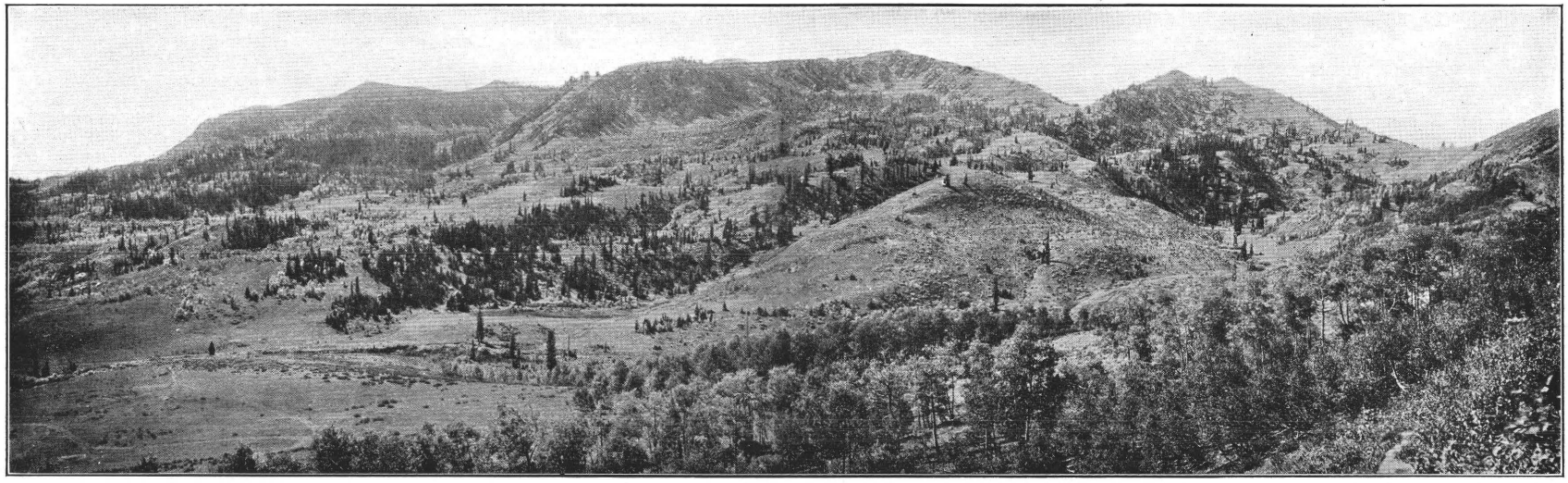
A. HOEN & CO. BALTIMORE

APPROXIMATE MEAN DECLINATION 1901



A. PARK CITY MONOCLINE.

Shows monoclinal structure of sedimentary formations, Weber quartzite in foreground, Park City formation capping first spur, Thaynes formation on the second and third cuestas, and heavy Triassic sandstone forming the prominent cuesta in right background, all dipping northwest. Park City in middle ground, Ontario mill in left foreground, and Silver King mine and Crescent Ridge in left background. Looking southwest.



B. CLAYTON PEAK DIORITE STOCK.

Diorite encircled by metamorphosed sediments lying to the right of Brighton Gap in right foreground and to the left of the gap at left. Glacial topography (cirques, roches moutonnées and moraines) developed on diorite.

shale, whose fauna does not differ conspicuously from that of the Thaynes, which lies below. Overlying the Ankareh shale is the basal part of the Nugget sandstone, whose age has not been definitely determined, but is either Jurassic or Triassic and which in the Park City district is represented by beds 515 feet thick. A few miles to the northwest of the district the Nugget sandstone is thicker and is overlain by the Twin Creek limestone of Jurassic age.

Plate V is a diagrammatic geologic column showing these formations as exposed in Big Cottonwood Canyon, a short distance west of Park City.

CARBONIFEROUS SYSTEM.

WEBER QUARTZITE.

Name and character.—About 30 miles due north from Park City and 1 or 2 miles west from Croydon station the great gray quartzite of the Wasatch section forms both walls of Weber Canyon. "It is from the characteristic occurrence of this remarkable bed of quartzite that the name Weber quartzite has been given to the body" by the geologists of the Fortieth Parallel Survey.[1] Critical stratigraphic and paleontologic studies lead to the conclusion that the great quartzite of the Park City district is the stratigraphic equivalent of the Weber quartzite. Among local mining men and in mining literature the formation has been called the "Ontario" quartzite, after the famous mine of that name which has been opened in it.

The Weber quartzite, as it outcrops in this region, consists of gray quartzite with comparatively insignificant occurrences of cherty patches and intercalated limestone. It is characterized by massiveness both in bedding, the beds being rarely less than 4 and in many places 8 to 15 feet in thickness, and in the absence of parting planes. On fresh fracture it is a light brownish gray, and it weathers to a glistening surface of a lighter shade. The normal quartzite is fine and even grained and dense. The exceedingly brittle nature of the rock causes it to break into sharp, irregular fragments, and when ground fine in a fracture zone it appears as a glistening white sugary filling inclosing larger fragments. (See Pl. XIX, *B*, p. 96.) It has been metamorphosed into quartz so completely that the granular form of the original sand is rarely discernible. The absence of impurities and cementing material has been demonstrated repeatedly by chemical analyses. Thus an analysis of this quartzite from Big Cottonwood Canyon shows 95.8 per cent of silica.

In a few small areas the normal quartzite appears to have been more thoroughly metamorphosed in patches so that the product is practically massive quartz with annular portions which resemble chert. This may be seen on the slope southeast of the Little Bell shaft and north of the Lucky Bill shaft. Another departure from the normal is seen in the thin intercalated grayish blue limestone which outcrops in Empire Canyon at the road level opposite and also above the upper reservoir. These beds bear some chert and weather to a gray and more arenaceous facies. They are relatively thin.

The middle and basal portions of this formation, which are not present in this area, outcrop in prominent cliffs just south of the district. Except for a few thin limestone beds near its top the middle portion is massive quartzite, but in the lower part the intercalated limestone members increase in number and thickness. In Big Cottonwood Canyon a few limestones are intercalated. A thin crinoidal sandstone occurs about 130 feet from the top, a thin pitted, cavernous, grayish-white quartzite 460 feet below that, and a thinly banded calcareous quartzite 430 feet farther down. In Weber Canyon this great formation is most characteristically exposed as a massive, dense, homogeneous quartzite. The insignificant exceptions are a curiously pitted and marked stratum of quartzite just below the top and a few thin limestones in the basal portions.

Distribution and thickness.—The main area of this formation exposed in the Park City district is an oblong tract, which extends south from Park City and Mountain Summit about 3 miles to Bald and Flagstaff mountains and has an average width of a mile. From Bald Mountain a much broken arm extends eastward between two great faulted zones, and to the

[1] King, Clarence, U. S. Geol. Expl. 40th Par., vol. 1, p. 161.

south and southwest about the east end of Bonanza Flat are isolated horses surrounded by intrusives. This quartzite forms the outcrops on the slopes which inclose Park City on all sides. It occurs standing up as knobs or massive blocks and as prominent broad spurs falling off precipitously. It is particularly well exposed on the salient bluffs west of the city, and is deeply incised by the canyons which lead south up to the mines. Characteristic outcrops have been revealed in Woodside Gulch along the King Road between the Alice and Woodside properties, in Empire Canyon near the adits to the Daly-Judge and the Alliance tunnels, and in upper Ontario Canyon.

The thickness of this formation in the Park City district can not be determined precisely, because nowhere within the area was a continuous exposure observed. The Ontario No. 3 shaft and workings cut Weber quartzite, dipping about 20°, to a depth of 1,620 feet, or a distance of approximately 1,500 feet. The collar of the shaft lies on the side of a canyon, which has been cut deep into the formation, and the thickness of quartzite that has been removed by denudation above this point is uncertain. It must be several hundred feet, as indicated by the position of the upper contact of the quartzite, which is exposed on the north and northwest. On the north side of Big Cottonwood Canyon there is an exposure of 1,340 feet. The thickness of this formation exposed within the district may be regarded as approximately 2,000 feet. The minimum thickness of the underlying portion may be 1,500 feet. An accurate determination of the total must await the working out of the structure and measurement of any possible great faults. Pending that it may be tentatively held as 3,500 feet. King and the geologists of the Fortieth Parallel Survey estimated the thickness exposed in Weber Canyon to be 6,000 feet, but they included basal red beds, which have since been differentiated as the Morgan formation.

Deposition.—Any satisfactory explanation of the deposition of 4,000 to 6,000 feet of quartzite calls for either unusual conditions or the maintenance of normal conditions for an unusual length of time. The detrital character of the material indicates a shore deposit, and its homogeneity shows the continuance of the same conditions during its deposition. Uniformly bedded structure points to the absence of currents or other disturbances, and cleanness of the product indicates thorough washing. The restricted area in which this study was made prohibits broad and specific deductions as to the mode of deposition of this formation. In brief, it appears that in the Park City area the Weber quartzite was deposited in relatively shallow quiet water not far from land and upon an evenly and constantly sinking sea bottom.

Age and stratigraphic relations.—The age of the Weber quartzite was regarded by the early geologic workers in this region as "upper Carboniferous" (Pennsylvanian). They did not base this conclusion on fossils found in the quartzite itself, but on its stratigraphic relation to fossiliferous limestones above and below. Direct paleontologic evidence obtained during the present investigation from the quartzite itself, from the limestones intercalated in its lower portion, and from the overlying limestone formations definitely proves the Pennsylvanian age of the Weber.

No fossils have been found in the quartzite beds of the formation within or adjacent to the Park City district, but in the season of 1903 Dr. T. W. Stanton collected Pennsylvanian fossils about 2 miles west of Croydon station, stratigraphically 1,800 to 2,000 feet below the top of the formation. Definite Pennsylvanian faunas were also obtained from limestones intercalated in the quartzite on the north side of Snake Creek, which underlies the part that outcrops in the Park City area. (See Pl. VI.)

From some more or less isolated limestones, again, Mississippian (Madison) faunas have been obtained. (See Pl. VI.) These can not possibly be included in the Weber formation, yet from the occurrence of other outcrops, from which no fossils have been obtained to distinguish them as Mississippian or Pennsylvanian, the stratigraphic treatment of these limestones is rendered very difficult, and for convenience they have been grouped together and mapped under one block as undifferentiated Carboniferous limestones. (See p. 49.)

Fossil-bearing beds	Section and diagrammatic profile	Lithologic character	Thickness	Formation	Age
		White sandstones with intercalated red shales	500 +	Nugget sandstone	JURASSIC OR TRIASSIC
		Red shales—locally sandy—with interbedded coarse gray sandstones Carries in lower portion *Aviculipecten weberensis, A. curticardinalis, A. parvulus, Myalina permiana* No economic importance	1150 + feet	Ankareh shale	
		Limestone, with sandstones and shales. "Mid-red" shale separates more calcareous upper from more arenaceous lower portion Carries large fauna, with many new fossil species, chiefly pelecypods, including Pentacrinus sp., *Myalina permiana, M. aviculoides, Aviculipecten curticardinalis, A. weberensis, A. parvulus, A. occidaneus,* Lingulas, Spirifers, Dentalia Forms country rock for replacement ore bodies and lodes	1190 feet	Thaynes formation	TRIASSIC
	Not exposed	Red shale, thinly bedded, fine grained Bears ripple marks, mud cracks, raindrop imprints No direct economic importance	1180 feet	Woodside shale	
	Covered	Limestone with interbedded quartzite, sandstones, and some shale Carries Lingulidiscina sp., *Productus cora,* Productus sp., *Plagioglypta canna, Euphemus subpapillosus,* Bellerophon sp. Forms country rock for principal bonanza replacement ore bodies	590 feet	Park City formation	PERMIAN ?
	Not exposed Not exposed				
	Float	Gray quartzite, massively bedded, homogeneous, dense Carries, in Weber Canyon, Lingula sp., *Productus subhorridus,* Schizodus sp., *Plagioglypta canna, Euphemus subpapillosus* Forms wall or walls of lead-silver lodes	1350 + feet	Weber quartzite	PENNSYLVANIAN. CARBONIFEROUS

0 100 200 300 400 500 Feet

DIAGRAMMATIC GEOLOGIC COLUMN, SHOWING FORMATIONS PRESENT IN STANDARD SECTION IN BIG COTTONWOOD CANYON.

PLATE VI.

PLATE VI.

Pennsylvanian species from limestones in the Weber quartzite near the Park City district.

Productus cora. This species occurs in limestones in the Weber quartzite, but a very similar one is found in the Madison limestone (Mississippian).

Figure 1. A large ventral valve. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. IV, fig. 3.)

Figures 2 and 2a. A small ventral valve seen from above and from the side and from the end. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. IV, figs. 4 and 4b.)

Productus inflatus?. This type occurs in the Weber quartzite, but one very similar to it is found in the Madison limestone.

Figures 3 and 3a. A ventral valve seen from above and from the side. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. III, figs. 1 and 1a.)

Figure 4. A specimen showing the two valves in their relation to one another. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. III, fig. 3.)

Composita subtilita. This type is found in the Weber quartzite, but one very similar to it occurs in the Madison limestone, although it is less abundant.

Figure 5. Dorsal view, showing the two valves in conjunction. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. VII, fig. 6.)

Figure 6. Another similar specimen. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. VII, fig. 4.)

Spirifer boonensis?. This species occurs in the Weber quartzite, but one hardly distinguishable is found in the Madison limestone. (See *Spirifer centronatus* below.)

Figure 7. Ventral and dorsal views of a specimen retaining both valves in their natural relation. (Copied from Prof. Paper U. S. Geol. Survey No. 16, Pl. VI, figs. 1 and 1a.)

Mississippian species from limestones in the Park City district.

Leptæna rhomboidalis. This is a typical Madison limestone species and it is fairly abundant in the Park City district.

Figure 8. Ventral view (?). (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. IV, fig. 4.)

Spirifer centronatus. A common Madison limestone species, which, however, is closely related to one found in the Weber.

Figures 9 and 9a. Ventral and dorsal views. (Copied from U. S. Geog. Surveys W. 100th Mer., vol. 4, Pl. IV, figs. 8a and 8b.)

Schuchertella inflata?. A common Madison limestone species, but a form closely resembling it occurs in the Weber.

Figure 10. View of a dorsal valve. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. IV, fig. 3.)

Euomphalus utahensis. A Madison limestone species fairly abundant in the Park City district. Is not found in the Weber quartzite.

Figures 11 and 12. Upper side of two specimens. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. IV, figs. 20 and 21.)

Straparollus ophirensis. Another Madison limestone species, sometimes rather abundant; unknown in the Weber.

Figure 13. Side view of a large specimen. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, fig. 26.)

Menophyllum excavatum. A Madison limestone species. Horn-shaped corals resembling this are abundant in the Park City district. A similar form may also be found in the Weber.

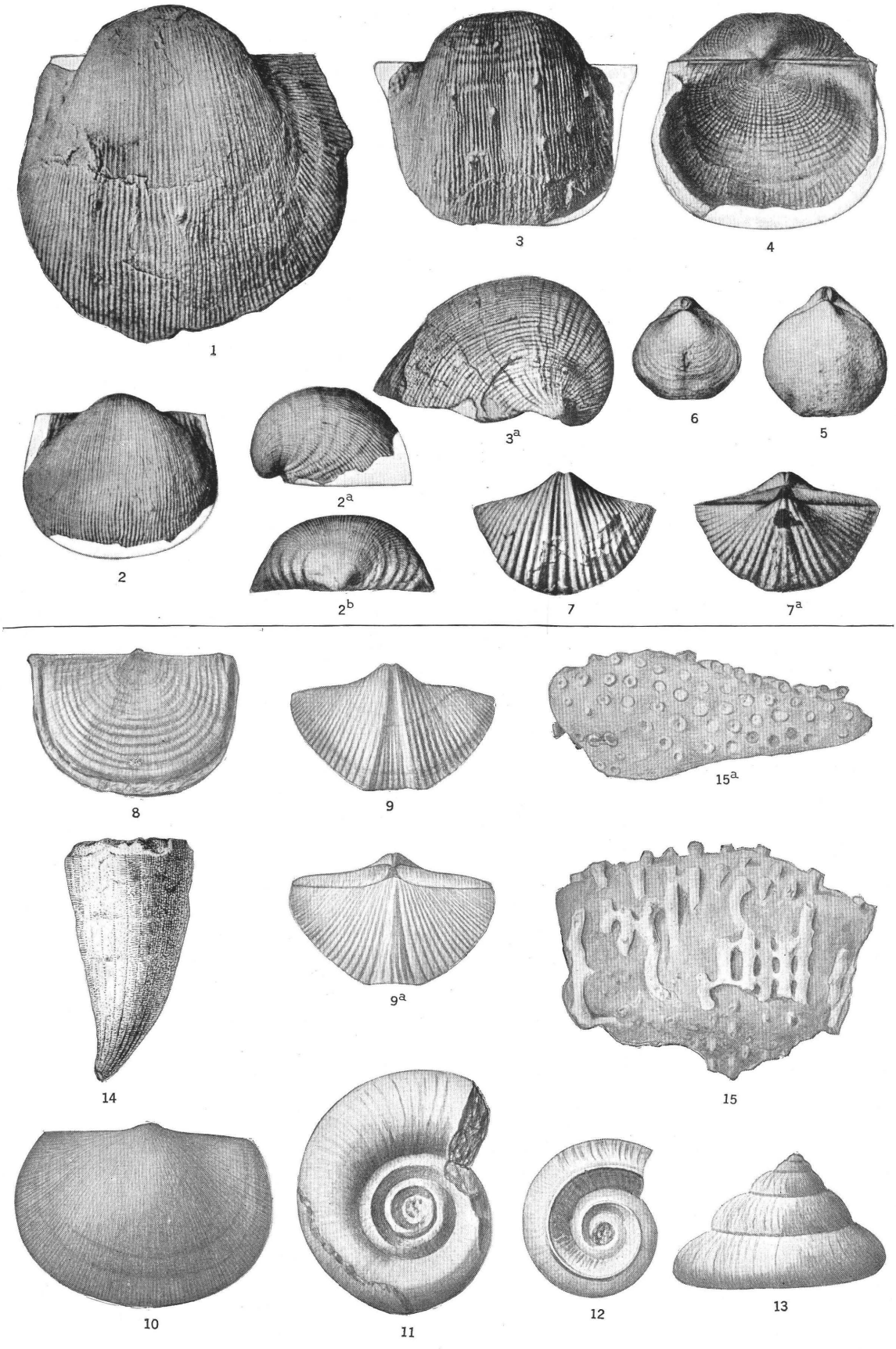
Figure 14. Side view. (Copied from Mon. U. S. Geol. Survey, vol. 32, pt. 2, Pl. LXVII, fig. 1a.)

Syringopora sp. A Madison limestone type. Tubular corals resembling this are abundant in the Madison limestone. A similar form may also be found in the Weber.

Figures 15 and 15a. Two views of a colony as it occurs partly filled in with rock. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, figs. 2 and 2a.)

Pennsylvanian (Weber) species

Mississippian (Madison) species



CARBONIFEROUS SPECIES FROM LIMESTONES IN THE PARK CITY DISTRICT.

In Weber Canyon the transition from the "Wasatch limestone" to the Weber quartzite is from gradually increasing siliceous beds in the limestone to varicolored sandstones (Morgan formation), which give way to quartzites alternating with limestones, finally coming to massive quartzite. In Snake Creek the passage upward and northward into the Weber quartzite is by a corresponding succession of limestones intercalated in quartzite.

The passage from this great quartzite into the overlying formation has been a subject of considerable study without definite results. One geologist reported that a marked uniformity existed between this quartzite and the overlying limestone. During the present survey, however, excellent exposures showed apparently complete conformity (Pl. XXIII, *A*, p. 104). The lithologic character of the sediments also indicated that a full record is here found of a normal gradual transition. Exposures in Woodside Canyon show a succession of calcareous sandstones, normal sandstones, and arenaceous quartzites immediately above characteristic massive Weber quartzite—apparently a normal transition. In Big Cottonwood Canyon, a few miles west of this area, the quartzite gives way upward to a sequence of sandy beds. In Weber Canyon the precise contact was not sufficiently exposed to demonstrate conformability, but the evidence obtainable pointed to that condition.

UNDIFFERENTIATED CARBONIFEROUS LIMESTONES.

Certain limestone members intercalated in the Weber quartzite and certain detached bodies, or "horses," of limestone inclosed in intrusive rocks are mapped separately as undifferentiated limestones. Exposures of these limestones are few and small.

They occur principally in the southeast corner of the area mapped, notably about the head of Cottonwood Canyon, thence northward to Glencoe Canyon and southward to Durey Hollow, westward along the slopes of that hollow and about the eastern wall of Bonanza Flat. The limestones vary from fine-grained dark-blue pure limestone, carbonaceous and arenaceous varieties, to entirely metamorphosed coarse white marble. The geologic age of some of these limestone masses is indicated by their stratigraphic position, namely intercalated in the Weber quartzite, and that of others by fossils. Those blocks which are intercalated in the quartzite are Pennsylvanian. Some of the collections from the detached blocks which have clearly been floated up from below include earlier forms than those from the intercalated limestones. Dr. Girty [1] finds some of them to be earlier Pennsylvanian and others Mississippian (Madison).

PARK CITY FORMATION.

Name.—The Park City formation has been named after the district, in recognition of the fact that it has yielded the bonanzas which during the last decade have made the district famous.

Character.—This formation is made up largely of calcareous members, but it also embraces several sandstones and quartzites. The ore-bearing limestones, in which interest naturally centers, their lithology, composition, and precise stratigraphic position, are considered in detail on pages 50–52. This formation characteristically makes knobs and spurs and moderately steep slopes intermediate in grade between those made by the resistant quartzite below and the nonresistant shale above. No good natural exposures of the entire formation are known in this area. The best surface exposures observed were afforded by the cut for the water pipe from the Alliance tunnel northward over the hill to the Silver King property. In general the formation comprises a thick limestone in its lower part, several minor limestones in its upper part, and a number of thin calcareous beds near the base, with intercalated quartzites and sandstones. The beds exposed in the Alliance cut are described on page 50.

[1] Letter to J. M. Boutwell dated June 22, 1910.

Alliance section of lower part of Park City formation.

	Feet.
Soil	10
White sandstone	60
Débris, white sandstone	70
Débris, gray fossiliferous limestone, chert nodules	10
Sandy limestone or calcareous sandstone débris.	
Massive gray limestone	15
Coarse yellow quartzitic sandstone	2–3
Covered	5
Massive blue limestone	4
Coarse yellow sandstone	5
Light-gray sandstone	5
Gray limestone becoming sandy upward	10
Massive blue limestone.	
Coarse gray sandstone	4
Gray sandy limestone	1
Brown sandstone	10
Actual contact with Weber quartzite not visible.	

This was the best exposed section observed in the district, but even this is open to correction owing to the probable repetition of beds at the base through both folding and faulting induced along the Fairview fissure. Along the King road the lower part of the formation is made up of normal gray limestones, cherty limestones, brown calcareous and shaly sandstone, and red, brown, and olive shales. The lower half of the formation includes two important limestone members and three minor quartzites. Overlying these and forming the top of Treasure Hill are siliceous beds of various types, sandstones, quartzites, etc.

The exposures a few miles to the west, in Big Cottonwood Canyon, present the best section observed.

Type section of Park City formation in Big Cottonwood Canyon.

	Feet.
Grayish-white limestone, with fine gray and white cherts increasing toward bottom	19
Shale and fine buff sandstone	19
Dark-gray limestone; thin chert, red shale, and porous loose member at base	7
Sandy shale	11
Yellowish-gray quartzitic sandstone changing into cherty white lime below	21
Gray and white banded chert with few white sandstone intercalations	52
Fine calcareous sandstone, with lentils of chert and brecciated fragments of sandstone	8
Float of buff sandstone and shale becoming more shaly and calcareous at base	104
Siliceous arkose comprising mainly rounded quartz grains and feldspars cemented with ferruginous material	18
Compact grayish quartzite	20
White compact sugary sandstone fossiliferous at base	8
Fine gray and pink massive quartzite with brown sandstonea nd gray-white chert bands near base	30
Light-gray limestone weathering whitish gray with an imbricated pattern; fine gray lime near base carries good faunas at two horizons in particular, 20 and 55 feet above the base	27
Gray calcareous sandstone	24
Fine gray limestone	9
Float showing bits of grayish and brown calcareous sandstone	36
Sandy limestone more calcareous at base with cavernous weathered surface	22
Float; upper sandy beds at top of Weber quartzite	31

Distribution and thickness.—The irregular and interrupted outcrop of the Park City formation extends around the center of the district in the form of an oxbow. It stretches from Bonanza Flat northward across the prominent eastern spur, passing the Daly West, Daly, and Silver King mines, thence northward to a point opposite Park City where it swings northeastward and eastward around north of the city, whence, continuing the curve, it reappears with a southerly strike as the east wall of Deer Valley, on Bald Eagle Mountain, and finally near the base of the eastern slopes of the range north and south of Cottonwood Canyon. The continuity of this general course has been much interrupted by intrusives, extrusives, and faulting, as will

be specifically described under "Structure" (pp. 94–98). Thus the J. I. C. and Quincy areas are separated by the Lucky Bill mass of diorite porphyry in middle Empire Canyon. In this vicinity the formation, which is apparently greatly thinned by faulting, is entirely covered by glacial deposits except where exposed by recent deep incisions of Empire Canyon and its fork just south of the Daly-Judge tunnel and the Massachusetts shaft. Between Empire Canyon and Walker & Webster Gulch not a single outcrop could be found. After being considerably offset between Empire and Woodside canyons, this formation reappears from beneath the glacial covering and strikes northward with a flat dip and consequently broader outcrop. It crosses Silver Creek in the northern part of the city and then extends eastward on the slopes north and northeast of the city. The principal exposures on the east side are that east of Deer Valley, crossed by the Heber road; a small one on the north slope of Bald Eagle Mountain, at the head of Frog Valley; and two small strips in the farthest southeastern part of the area. The most extensive and characteristic exposures are those lying west and east of Park City, forming respectively Treasure Hill and Twin Knobs.

A mass of this formation which does not outcrop and has not been previously recognized occurs north of McHenry Canyon under the eastern slope of Bald Eagle Mountain. The economic possibilities of this great ore-bearing formation, particularly in the vicinity of intrusive rocks and fissures, warrants the special mention of this occurrence. Its burial beneath the overthrust mass of Bald Eagle Mountain is described under "Structure" (p. 96).

The exposures in this area do not afford a basis for a close estimate of the thickness of the Park City formation. Crosscuts in the Silver King and Daly West mines should, under normal conditions, yield the desired data, but strike faulting in both properties has so complexly duplicated the succession as to render measurement of the beds well-nigh impossible. The total thickness indicated by the Treasure Hill body is approximately 700 feet. The only reliable section observed is the type section in Big Cottonwood Canyon, and the thickness at this point, including the beds above the Weber quartzite and below the red shale, measured 590 feet.

Deposition.—The conditions which prevailed during the deposition of this formation, a few hundred feet in thickness, marked the transition from those under which the great thickness of sandstone had been laid down to those which followed, when the sediments formed red shale. The composition of the limestones, sandstones, and shale points to their deposition in comparatively shallow water and the limestones contain shallow-water animal remains. The repeated alternation of these lithologic types shows unsettled conditions either as regards elevation or deposition along shore, and it is probable that both occurred.

Age and stratigraphic relations.—The fauna of the Park City formation, which is better known from areas in Idaho, Wyoming, and other parts of Utah than from the Park City district itself, may be properly limited to two facies—one which is best known in the dark phosphatic and calcareous shales around Montpelier, Idaho, and one which occurs in the limestones that at some points overlie these shales and at others seem largely to replace them. The fauna of the phosphate shales and limestones has been described in United States Geological Survey Bulletin 436. The fauna of the limestones is characterized by the remarkable species *Spiriferina pulchra*, with which are associated types of Productus, Bryozoa, etc. Both faunas are suggested by the collections from the Park City district, the one by more or less abundant *Lingulidiscina utahensis;* the other by Spiriferinas, probably referable to *S. pulchra.* The age of these faunas is now provisionally determined as Permian. Some of the organic remains of the Park City formation are shown on Plate VII.

No unconformity was observed with the underlying Weber quartzite or the overlying shale or within the formation. Accordingly it would seem that sedimentation proceeded unbroken from Mississippian time through that part of the Pennsylvanian which is represented by the Park City formation.

On a comparison of the position of the ore-bearing limestones of this formation with that of others in Utah mining camps, they appear to be somewhat higher than the Highland Boy, Commercial, and Jordan limestone members of the Bingham quartzite of the Bingham district

(regarded as equivalent to the upper portion of the Weber quartzite); higher than the "Great Blue" limestone of the Mercur district (Mississippian or "Lower Carboniferous"); higher than the Mammoth ("Eureka") limestone (Mississippian) and Godiva limestone (assigned to the Pennsylvanian) of the Tintic district; and higher than the great limestone of Emma Hill, at Alta, in Little Cottonwood Canyon (Mississippian). Thus the Park City formation is much younger than any of the other limestones in Utah that bear ore bodies except possibly those at Bingham, and it is believed to be younger than the ore-bearing limestones of the Bingham district.

TRIASSIC SYSTEM.

WOODSIDE SHALE.

Name.—The Woodside shale is named from Woodside Gulch, at the head of which, on the west slope, is the best exposed section of these sediments in the district.

Character.—This great formation is a lithologic unit, being composed without material exception of fine-grained dark-red shale. In some places a shaly parting gives way to very thin laminations, and here and there a slight increase in coarseness of texture produces a fine-grained sandstone, or the color varies to buff, brown, and gray. The characteristic topographic form that has developed on this homogeneous formation is an even, uninterrupted slope, which is, as a rule, densely overgrown with grasses, shrubs, and aspen.

The formation has no direct economic importance, as it affords neither ore bodies nor building stone. Indirectly, however, its enormous capacity for water renders it an important factor in mining operations.

Distribution and thickness.—The Woodside shale appears in this district in three principal areas. In a highly metamorphosed condition it forms the spotted dark-red and green argillite on the north face of Jupiter Peak and extends northward along the east side of Pioneer Ridge. Again it makes the metamorphic argillite in the gap next west of Lucky Bill Gap; it descends the north side of the Quincy spur and reappears in its normal state northwest of the Daly West shaft and it strikes thence northward along the west side of Empire Canyon to the fault gulch opposite Daly No. 2 shaft. It is seen in its typical state in the slope above and west of the Silver King mines, whence it extends north along the west side of Nigger Hollow. West of Park City it appears, striking south, on the eastern slope of the east wall of Deer Valley Meadow and Frog Valley, and disappears at the head of Pocatello Gulch. The third locality in which it is found is an irregular V-shaped outcrop on either side of Cottonwood Canyon.

The thickness of this shale varies considerably. In the type section in Big Cottonwood Canyon this formation was found to be 1,090 feet thick. In the Park City district the best opportunity for its determination was afforded by the deep shaft of the Silver King Consolidated Co., although possibly inaccurate owing to faulting. This shaft is located on the northeast side of Crescent Ridge just over the divide northwestward from the Silver King property. It passed through the red Woodside shale for 800 feet, which, by reckoning that the average dip is 30° and that the collar lies 30 feet below the upper contact, affords a corrected thickness of 700 feet.

Deposition.—The varying conditions under which the Park City formation was deposited were followed by a long-continued period of quiescence. The fine detrital material composing the sediments and the presence throughout their great thickness of ripple marks, mud cracks, and rain-drop imprints indicate their deposition along a shore.

Age and stratigraphic relations.—No fossils were found in this shale, nor was any stratigraphic evidence seen which would correlate the formation with either the one below or that above it. Lithologically, however, this shale finds its equivalent in an important member and several thin ones in the next overlying formation and in the great thickness of red shale succeeding that. This resemblance shows that the conditions under which this formation was deposited were those that prevailed during the time of the succeeding rather than of the preceding formation, and remains found in this formation at the north closely resemble those of the overlying next later formation. Accordingly the Woodside shale will be grouped with the overlying fossiliferous formation as of Lower Triassic age.

PLATE VII.

PLATE VII.

Species from the Park City formation in the Park City district.

Lingulidiscina utahensis. A species rather common in and characteristic of the Park City formation. The figures represent the lower valve. The upper has the shape of a low, rapidly expanding cone, so tilted that the apex occurs behind the middle.

Figures 1 and 1a. A dorsal (lower) valve, natural size and × 2. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. X, figs. 3 and 3a, where they are erroneously included with the Triassic.)

Lingula carbonaria?. A rather common fossil in the Park City formation, rarely found above or below it in the Park City district.

Figure 2. A dorsal valve. (Copied from Bull. U. S. Geol. Survey No. 436, Pl. I, fig. 4.)

Productus eucharis. A species not known to occur outside of the Park City formation.

Figures 3, 3a, 3b. A ventral valve seen from above, from the side (in outline), and from the front (× 2). The dorsal valve is flatter and crossed by strong transverse wrinkles. (Copied from Bull. U. S. Geol. Survey No. 436, Pl. II, figs. 4, 4c, 4b.)

Plagioglypta canna. These long, slender, tapering cones are very common in the Park City formation and extremely characteristic of it.

Figure 4. Side view of an imperfect specimen. (Copied from Bull. U. S. Geol. Survey No. 436, Pl. VI, fig. 14.)

Euphemus inspeciosus. A large Euphemus, probably the same species as that illustrated, is characteristic of the Park City formation but is less common than *E. subpapillosus* (fig. 6).

Figures 5, 5a, 5b. Apertural, opposite, and side views of a somewhat imperfect specimen. (Copied from U. S. Geog. Surveys W. 100th Mer., vol. 3, Suppl., Pl. IV, figs. 1a, 1b, and 1d.)

Euphemus subpapillosus. This species is fairly common in the Park City formation and characteristic of it. In many places it occurs in association with *Plagioglypta canna.*

Figure 6. Side opposite the aperture. (Copied from White's "Contributions to invertebrate paleontology," No. 6, Pl. XXXIV, fig. 3a.)

Leda obesa. This species, or one very closely related to it, occurs in the Park City formation, of which, though rather rare, it is characteristic.

Figures 7, 7a. A specimen seen from the side and from above. (Copied from White's "Contributions to invertebrate paleontology," No. 6, Pl. XXXIV, figs. 2a and 2b.)

Spiriferina pulchra. This species is not very abundant in the Park City formation, but it is very characteristic of it. It can readily be distinguished from the Spirifers of the Weber and Madison formations, by the fact that the shell is finely porous or spongy and that the median portion of the valves, technically called the fold and sinus, are not marked by ribs as in the other species.

Figures 8 to 8d. Views of three specimens. 8, A dorsal valve; 8a, a ventral valve; 8b, 8c, 8d, back, front, and side views of a specimen retaining both valves. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. XII, figs. 12–12d.)

Species from the Thaynes formation in the Park City district.

Myalina permiana?. This is a common and characteristic fossil of the Thaynes formation.

Figure 9. Side view. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, fig. 7.)

Sedgwickia? concava. This form also is rather common in and characteristic of the Thaynes formation.

Figure 10. Side view. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, fig. 3.)

Aviculipecten wasatchensis. This species of Aviculipecten, together with the others following it, is very characteristic of the Thaynes formation. The fossils of this formation consist very largely of pectenoid shells, some of which are shown here, though many are yet to be described. Most of them are small shells, but some attain a size of 2 inches or more.

Figures 11 and 11a. A small left valve from the Thaynes formation in the Park City district, natural size and × 3.

Aviculipecten boutwelli.

Figures 12 and 12a. Specimen from the Thaynes formation in the Park City district, natural size and × 2.

Aviculipecten thaynesianus.

Figures 13 and 13a. Specimen from the Thaynes formation in the Park City district, natural size and × 2.

Aviculipecten occidaneus.

Figures 14, 14a, 14b. Three specimens from the Thaynes formation. Figure 14a, × 2. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. XII, figs. 13–13b.)

Aviculipecten parvulus.

Figure 15. A specimen from the Thaynes formation, × 3. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, fig. 6.)

Aviculipecten curticardinalis.

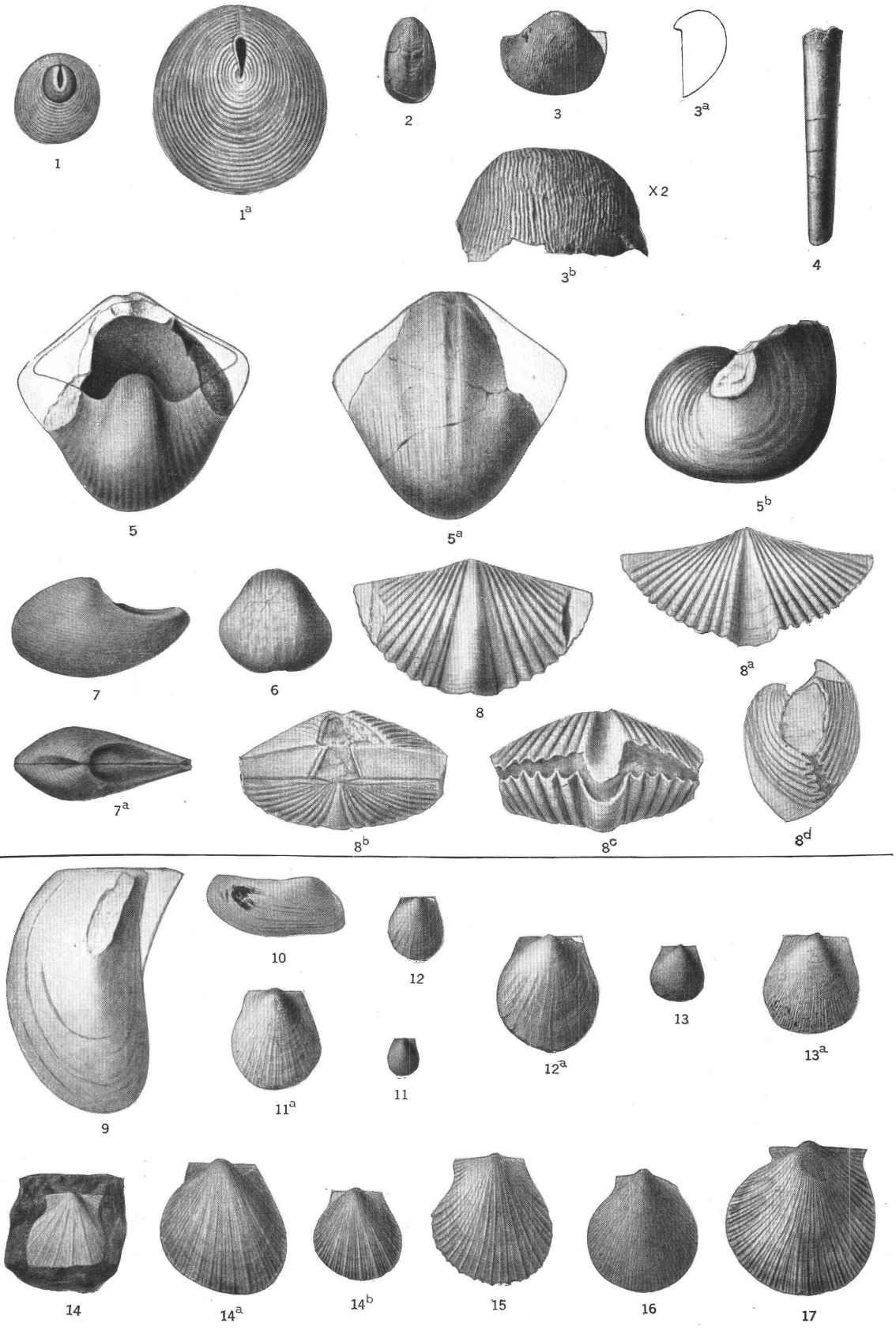
Figure 16. Side view of a specimen from the Thaynes formation, × 2. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, fig. 4.)

Aviculipecten weberensis.

Figure 17. Side view of a specimen from the Thaynes formation. (Copied from U. S. Geol. Expl. 40th Par., vol. 4, Pl. VI, fig. 5.)

Park City formation (Permian?)

Thaynes formation (Lower Triassic)



CHARACTERISTIC SPECIES FROM THE PARK CITY AND THAYNES FORMATIONS IN THE PARK CITY DISTRICT.

THAYNES FORMATION.

Name.—The Thaynes formation is named after a canyon whose deep and extended incision affords the best exposures of this formation within the district.

Character.—This is essentially a calcareous formation. It comprises two parts separated by a red shale member, each made up of limestone, calcareous sandstone, normal sandstone, and shale. Most of the true limestones are in the upper part, and the sandstones predominate in the lower. A characteristic rock occurring at many horizons in the formation is a dense, homogeneous, blue-gray, calcareous sandstone, which appears superficially to be a limestone, but on exposure to the weather loses its low calcareous content and becomes a medium fine-grained, brown sandstone. This rock forms some of the richest fossiliferous members of the formation. These members, the abundant and characteristic fossils, and the red shale member—the "mid-red" shale—serve to distinguish this formation readily from the Park City formation. Its outcrop forms abrupt cliffs, and the dip slopes and basset edges make broad, flat slopes. These characteristics are well shown by the spur descending from Crescent Ridge northward to Thaynes Canyon, and by that part of the ridge lying between Nigger Hollow and Thaynes Canyon. Its surface is brushy and ledgy. No exposure which was not too complexly faulted, intruded, or metamorphosed to serve for a standard section was found within the district, although a number of partial sections in Thaynes and Empire canyons were carefully measured and studied for the fullest evidence available in the vicinity of the mines. About 3 miles west, in the north side of Big Cottonwood Canyon, excellent unbroken exposures of this formation occur in several parallel spurs. The sequence, fossil and lithologic characteristics, and thickness of the strata in that locality are briefly stated below.

Section of Thaynes formation in Big Cottonwood Canyon.

	Ft.	in.
Sandstone, massive, even, fine grained, basal member of Argenta formation.		
Limestone, blue, locally sandy, fossiliferous	1	
Shale, fine, gray-green	12	
Limestone, blue-gray, cavernous, fossiliferous		5
Limestone, transition from shale through sandstone, fossiliferous	2	6
Sandstone, gray-brown, with calcareous shale intercalations, fossiliferous	14	
Shale, maroon, fine banded	5	
Limestone, gray, impure, semicrystalline, fossiliferous		6
Limestone, light gray-blue, massive, sandy, fossiliferous	24	
Shale, gray-brown	16	
Limestone, impure, gray, massive, fossiliferous	5	
Shale, gray to buff	4	
Sandstone, massive, gray-brown; vertical sheeting; fossiliferous	14	
Shale and sandstone, green to brown; calcareous intercalations	42	
Sandstone, gray, finely laminated; chert lenses	4	
Shales	8	
Limestone, fine, blue, with intercalated ripple-marked sandstones, lenticular gray cherts, and biotitic fossil-bearing bed	20	
Shale, olive	15	
Sandstone, olive-gray, massive; weathers rusty; trails, fucoids, and imprints	4	
Limestone, bluish; matrix inclosing "tangle" stringers of ferruginous sandstone	5	
Limestone, impure, blue, very fossiliferous	4	
Shale, olive, fine grained	19	
Limestone, sandy and shaly	7	
Limestone, blue to gray; spheroidal weathering; fossiliferous	8	
Débris, lime with intercalated shale	14	
Limestone, dark blue, locally shaly; weathers rough; several highly fossiliferous layers	14	
Shale, brown, inclosing sandy bed	10	
Limestone, gray-blue; gray chert lenses; fossiliferous	5	9
Shale, brown with green tinge	4	
Limestone, coarse shells; gray chert band	6	
Limestone, dark blue, sandy, massive	14	
Limestone, deep blue; weathers rusty; fossiliferous	35	
Sandstone, calcareous, rusty; breaks in slabs	11	

	Ft.	in.
Limestone	10	
Sandstone, gray-black, shaly, with bands of black slaty shale; fossiliferous	66	
Sandstone, calcareous, finely laminated, highly fossiliferous	168	
Shale, maroon	20	
Float, varicolored shale	30	
Shale, green, buff, olive, maroon, yellow	64	
Sandstone, gray, calcareous; intercalated shales	34	
Limestone, gray; intercalated calcareous gray sandstone	5	
Sandstone, greenish brown; intercalated shales	14	
Limestone, gray-blue, fossiliferous	4	
Shale, olive, with three fossiliferous argillaceous limestones	17	
Limestone	5	
Limestone, blue; shale, olive-brown; sandstone, calcareous; alternating series, varying much in color and texture; fossiliferous	370	
Talus, containing shale regarded as top of Woodside shale.		

Distribution and thickness.—The Thaynes formation is one of the two most extensively exposed formations in this district. On the western flank of the Park City anticline it forms both of the inclosing walls of Thaynes Canyon from head to mouth and all of the middle and headward parts of Whitepine Canyon, and thence strikes southwestward into Big Cottonwood Canyon. It is again seen in the main fault zone of the district overlying the great mines. There it forms the prominent ledges west of the upper portion of Empire Canyon, opposite the Daly mine, the spur extending from the Daly West mine to Morgan Knob, and the cliffs which overlook the Daly Judge amphitheater. On the eastern flank of the anticline the cropping of this formation is exposed about the heads of Heber, McCune, and Pocatello gulches, and at the extreme southeast appears in a triangular area just north of Cottonwood Canyon.

The best measure of the thickness of this formation was obtained in Big Cottonwood Canyon, where, as shown above, the upper part amounts to 630 feet, the middle red shale to 115 feet, and the lower part to 445 feet, the whole formation thus aggregating 1,290 feet. Within the Park City area proper no exposure was found suitable for measurement. The difference in thickness of exposures of this formation on the east and west sides of the district may be apparent rather than actual. On the Heber road near the top of the eastern exposure red shale crops out which is probably the middle red shale, and there is also red shale near the top of the Cottonwood exposure. It would thus appear that the eastern exposures embrace a portion of the formation only—that is, the part lying below the middle red shale—the upper portion being either truncated by intrusives or buried by extrusives.

Deposition.—The deposition of the beds of this formation was preceded and followed by the deposition of great thicknesses of red shale. The accumulation of limestone and coarser detrital deposits probably means that during this interval this area suffered depression, but that this depression was comparatively small and only temporary or intermittent is clearly proved by the shallow-water fossils and by the presence at the middle of the formation and scattered from top to bottom of detrital shore deposits—varicolored shales. Further, during some of these movements the land rose sufficiently to stop deposition and to permit erosion. This is shown by a contact observed on the northwest slopes of Morgan Knob, where a fossiliferous gray limestone unconformably overlies a fine-grained cherty quartzite and fills inequalities 18 inches in depth which are apparently due to erosion. In brief, this period was probably characterized by crustal instability—the land frequently rising above and sinking below the sea.

Age and stratigraphic relations.—The fauna of the Thaynes formation consists almost entirely of pelecypods of which small pectinoid shells form an important part. Some of these species have been described but many of them are new. The age of the formation, as explained in detail below, is probably Lower Triassic.

The general aspect of the fauna is shown by a list of species given by King[1] as coming from the "Permo-Carboniferous" beds. Most and perhaps all of these were obtained from the

[1] U. S. Geol. Expl. 40th Par., vol. 1, 1878.

horizon of the Thaynes formation. On the page cited and on pages 164 and 173 of the same volume King gives these forms as from the "Permo-Carboniferous," but in the paleontologic volume (vol. 4) of the same series of reports the horizon is given as "Upper Coal Measure limestone (Permo-Carboniferous)." As King employed the term "Upper Coal Measure limestone" for a distinct formation below the "Permo-Carboniferous," it is clear that the paleontologist did not use these terms with the same meaning as King.

In the reports of the Fortieth Parallel Survey the Weber quartzite in the Wasatch Mountains section is said to be followed consecutively by the "Upper Coal Measure limestone," the "Permo-Carboniferous," and the Triassic. King's list of "Upper Coal Measure" species consists, essentially, of types characteristic of the Park City formation, just as his list of "Permo-Carboniferous" species consists of types characteristic especially of the Thaynes formation. The two lists contain no species in common and this is in accord with more recent investigations which show a complete faunal change at the base of the Woodside. From these facts and from the thickness of the "Upper Coal Measure limestone" it seems probable that that terrane includes not only the Park City formation but also the Woodside shale of the Park City district.

In his general statement King assigns to the "Upper Coal Measure limestone" a thickness of 1,700 to 2,100 feet, and Emmons, writing especially of the Weber Canyon section, says that for 1,600 or 1,700 feet above the Weber quartzite the rocks contain "Coal Measure" fossils, whereas for 700 feet above, to the Triassic red sandstone, they contain "Permo-Carboniferous" fossils. As against this the Park City formation has a thickness of but 590 feet. No such thickness of beds containing the Park City fauna is found in either region above the Weber quartzite, and the most probable explanation appears to be that only the lower portion of the "Upper Coal Measure limestone" represents the Park City formation, the rest being Woodside, which, however, is not limestone but shale.

The "Permo-Carboniferous" fauna is especially characteristic of the Thaynes (the Woodside being almost unfossiliferous in this region), and it seems fairly safe to conclude that the 700 or 800 feet of beds in the Weber Canyon section containing that fauna are Emmons's "Permo-Carboniferous" on the one hand and the representative of the Thaynes formation of the Park City district on the other. Typically the Thaynes formation has a thickness of 1,190 feet and probably 200 feet or more of argillaceous sandstone in Weber Canyon distinguished from the softer Woodside shale below and apparently included in the "Upper Coal Measure limestone" should be added to it.

In Weber Canyon, above the calcareous beds carrying pectens and myalinas and apparently corresponding closely to Emmons's and King's "Permo-Carboniferous" and below the typical red beds, occur approximately 1,000 feet of strata which probably correspond to the Ankareh shale of the Park City section. Emmons and King appear to have included these rocks and the overlying Nugget sandstone in their Triassic.

Thus, in Emmons's and King's general section for the Wasatch Mountains the Park City and Woodside formations appear to have been included in the "Upper Coal Measure limestone." The Thaynes appears to correspond to the "Permo-Carboniferous" (possibly with some additions from the "Upper Coal Measure limestone") and the Ankareh and Nugget appear to have been included in their Triassic.

In the Park City district the Thaynes formation has furnished the following so-called "Permo-Carboniferous" (Lower Triassic) types:

Pentacrinus sp.
Myalina permiana.
Myalina aviculoides.
Aviculipecten curticardinalis.
Aviculipecten weberensis.
Aviculipecten parvulus.
Aviculipecten occidaneus.

Besides these there are numerous other pelecypod forms, most of which are yet to be described.

The Myalinas, Aviculipectens, and a species of Lingula are almost universally present throughout the Thaynes formation, and Pentacrinus, another valuable index, is limited to the part lying above the middle red shale. These forms with some others are pictured on Plate VII.

In southern Idaho the stratigraphic equivalent of the Thaynes formation contains, besides a number of identical or very similar pelecypod forms, an abundance of ammonites, of which Meekoceras types are perhaps the most conspicuous and the best known. This Meekoceras zone is the typical Lower Triassic of North America, and there seems little reason to doubt the Lower Triassic age of the Thaynes formation if the Meekoceras zone of Idaho has been correctly assigned to that period.

In its stratigraphic relations the Thaynes formation is intimately related to the two inclosing shale formations. The same conditions that prevailed during their deposition existed also while the shale beds of this formation were deposited. No great unconformity either above or below was noted, though a small unconformity due to erosion was observed at one horizon within the formation and others doubtless exist.

The persistence of certain members of the Thaynes formation is remarkable. Thus the middle red shale, having a thickness of only 115 feet in the Park City area, is found 3 miles west in the Big Cottonwood locality and 40 miles north in Weber Canyon. Still more noteworthy is the occurrence of thin limestones in the same stratigraphic positions and bearing identical fossils in this district and again in the Big Cottonwood section. Not enough work in following special members was done to warrant the affirmation that this persistence is actual stratigraphic continuity, though this is doubtless true, and if so it indicates that the conditions under which these members were formed were brought about by land movements of equal amount throughout the region.

ANKAREH SHALE.

Name.—The Ute word Ankareh, meaning red, was given by the writer to the ridge on which the shale formation overlying the Thaynes is most characteristically developed, and it thus supplies an appropriate geographic designation for the formation.

Character.—The Ankareh is composed of siliceous detrital deposits, which form chiefly red shales that in places are sandy through considerable thicknesses. It includes a number of well-marked beds of coarse gray sandstone, which range from 20 to 55 feet in thickness. A few fossiliferous grayish-blue limestones are also intercalated, but these are only a few feet thick. The division between this and the underlying formation is made on lithologic grounds, calcareous members characterizing the Thaynes formation and siliceous members characterizing the Ankareh formation. The basal member of the Ankareh is the coarse massive sandstone which lies at the base of the red shale as a whole and immediately overlies a thin limestone. The top is defined by the massive white sandstone of the overlying Nugget. The nonresistant character of the beds of this formation as a whole produces even slopes along its outcrop, broken by benches on the sandy members and usually covered with aspen, rank grasses, and brush. The beds rarely contain water, and neither ore nor stone of economic value has been found in them.

Distribution and thickness.—The formation outcrops at only two localities within the district. The principal one is an N-shaped zone at the mouth of Thaynes Canyon, where it forms the crest of the west wall, then descends across the mouth of Whitepine Canyon and forms the spur west of Whitepine. Thence it strikes westerly and is plainly visible on each of the succeeding ridges which head at Big Cottonwood Canyon. The second area, not heretofore recognized, is on Pioneer Ridge, between Crescent Ridge and Jupiter Hill. The red shale that forms the spur between the Kearns-Keith or Sampson amphitheater and the Jupiter amphitheater immediately to the south belongs in the Ankareh shale.

The best exposure for measurement is the one at Thaynes Canyon, but this is incomplete and not fully accessible, and owing to the probability of deformation by faulting any estimate of the thickness would be of little value. In the standard Big Cottonwood section the thickness of the part which crops out in the Park City district was found to be 1,150 feet.

Deposition.—These shallow-water detrital deposits mark the end of the next to the last period of conditions favorable to calcareous deposition and the resumption of those shore conditions that followed Mississippian time, were interrupted during the deposition of the Permian (?) limestones, and prevailed from that time on. These changing conditions point to the gradual though occasionally fluctuating elevation of this area from beneath deep seas to mountain heights. A full consideration of the details of stratigraphy and paleontology and their bearing upon the geologic history of this region is hardly germane to a report of this character.

Age and stratigraphic relations.—The age of the Ankareh shale, so far as indicated by meager paleontologic evidence, is Lower Triassic. The fossils on which this determination is based comprise three lots from the Big Cottonwood locality and fragmentary collections from the Park City district. The lowest two lots, one from coarse sandstone and the other from a thin limestone, both within 200 feet of the Thaynes formation, show a general agreement with the Thaynes fauna. This appears to fix the age of the lower part of the Ankareh shale as Triassic, and for the present purpose the part of this formation which lies within this district may be considered as of that age. The determination of the age of the upper part may be left to future workers in adjacent areas where the complete section is exposed.

Doubtless deposition took place without interruption throughout the period represented by these Triassic formations. The transition upward into sandstones which are well bedded and also coarsely cross-bedded points to probable depression from shore conditions to slightly deeper water and strong currents.

JURASSIC OR TRIASSIC SYSTEM.

NUGGET SANDSTONE.

About 500 feet of white sandstones with some intercalated reddish shales complete the stratigraphic section in this district. These were originally grouped with the Ankareh shale, but subsequent work in adjoining areas, in which the overlying beds are well represented, makes it apparent that they represent the lower part of the upper portion of the Nugget sandstone, named and described by Veatch [1] from Nugget station, Wyoming, and further described and mapped in connection with the investigations of phosphate deposits in Idaho, Wyoming, and Utah.[2] Veatch's Nugget formation included at the base about 600 feet of reddish strata which properly belong to the Ankareh shale, and in all later reports the name Nugget has been restricted to the upper heavy white sandstones, which also include some shale beds. The beds here correlated with the Nugget sandstone outcrop on the ridges east and west of Iron Hollow, in the extreme northwest corner of the district. The age of this formation is not definitely established, but is either Jurassic or Triassic. Overlying these sandstones is a succession of fine-grained gray limestones several hundred feet in thickness which yielded organic remains that prove them to be of Jurassic age.

QUATERNARY SYSTEM.

CLASSES OF DEPOSITS.

The accumulations of loose material found in most of the valleys of the district have assumed their present position and form partly through the immediate action of ice, partly by deposition in water, and perhaps partly through slides of surficial rock. In localities where these deposits overlap, it is not always possible to distinguish the ice-laid material from that deposited in water or by other means, but isolated deposits may be readily distinguished. As far as possible, the three classes of material resulting from glaciation, sedimentation, and landslides will be discussed separately.

[1] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming: Prof. Paper U. S. Geol. Survey No. 56, 1907.
[2] Gale, H. S., and Richards, R. W., Phosphate deposits in Idaho, Wyoming, and Utah: Bull. U. S. Geol. Survey No. 430, 1910, p. 457.

GLACIAL DEPOSITS.

Distinct evidences of ice action are confined to the northern, southern, and western drainage basins of the district, which are roughly outlined by the county boundaries. If glaciation were ever general in these basins, however, there are now no undoubted signs of it. Not only are the peaks craggy and rough, but the long, sloping ridges are largely free from the scourings and droppings incident to ice erosion. Nevertheless, the high places were no doubt snow-covered and held the material for the glaciers which appear to have been confined to locations of subordinate elevation.

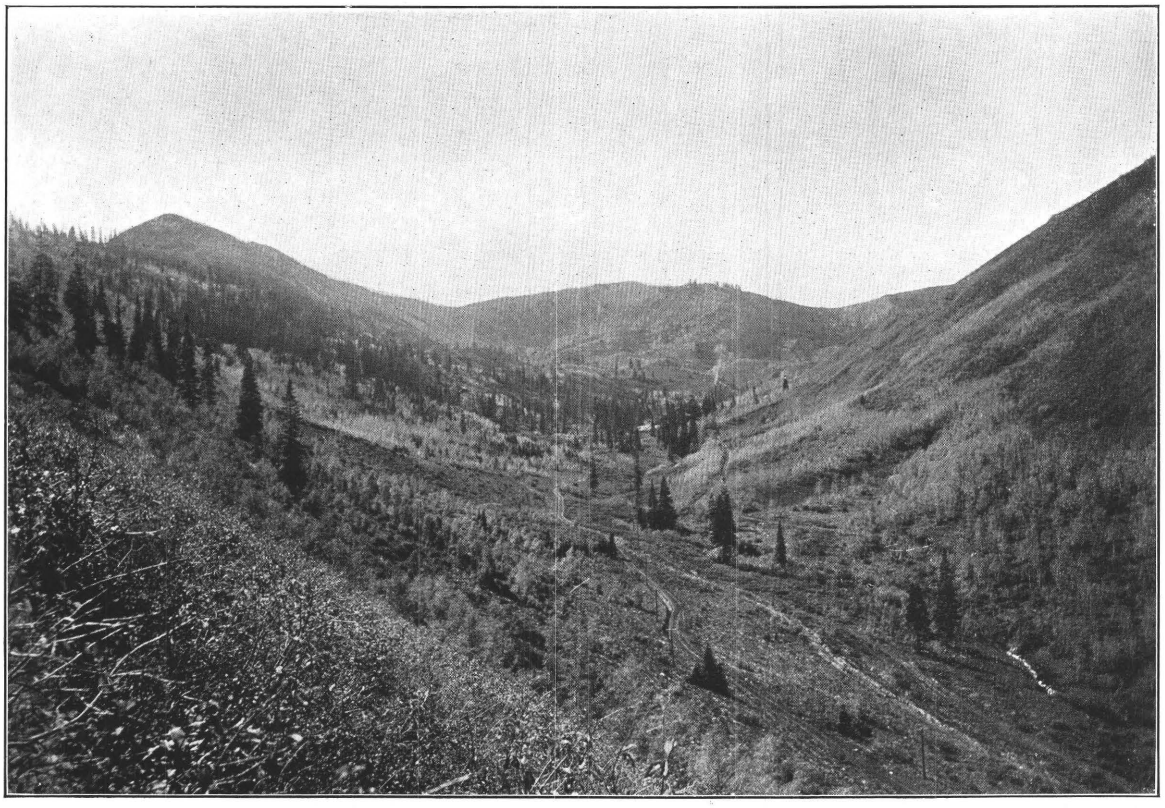
Evidence of glaciation is found mainly in the canyons that roughly radiate from Clayton Peak, but this regularity is broken in places, such as Jupiter and Scott hills, where they head in subordinate spurs. All the valleys extend beyond the boundary of the area mapped and in fairly straight lines, except Walker & Webster Gulch, which bends and joins Empire Canyon. In topography also they are similar, being generally open, broad valleys. Bonanza Flat is an example of extreme breadth, and Empire Canyon is exceptionally narrow in its lower course.

As to general geology, the valleys of the north slope incise sediments dipping to the north or northeast and including all formations from the Weber quartzite to the Nugget sandstone. The canyons of the south and west slopes, however, head in the Clayton mass of diorite and continue across the contact into sediments.

Perhaps the most general evidence of ice action in these valleys is their form, all being U shaped in cross section except the lower course of Empire Canyon, which is distinctly V shaped below the Massachusetts mine. This U form is particularly notable in the upper parts of the valleys and appears to extend downward farther in northward-facing canyons than in those opening to the south. The sides of the valleys are commonly smooth, even slopes more or less covered with vegetation, though rarely tree-clad. Notable exceptions are Whitepine Canyon, embayed by cirques and set with intermediate spurs; Empire Canyon, greatly broken by lateral valleys; Thaynes Canyon (Pl. VIII, *A*), fluted by eastward-facing ravines; and Bonanza Canyon, bordered by wavy slopes. The broad floors of the valleys have generally smoother surfaces in their lower than in their upper portions. The floors of many of the southward-facing canyons drop off with steep slopes into V-shaped gorges. Thaynes and Empire canyons, however, being relatively smooth at their heads and narrow and steep farther down, show none of these characteristics. The heads of nearly all the glaciated canyons are more or less inclosed by a circular wall of rock, generally craggy and precipitous.

Valleys of this description—U-shaped, even-sided, smooth in their lower courses, corrugated in their upper portions, headed by high-walled cirques—are topographically like certain valleys that are known to have derived their full round curves from glaciation. In addition to the topographic features striations on bedrock are found in some of the canyons. They were seen in the central area of Whitepine Canyon, at the head of Bonanza Canyon, and on the north side of Lone Hill. In Whitepine Canyon the bare rock midway of the valley is furrowed and grooved, sandstone and limestone alike, in line with the general trend of the valley. There are minor scratches, however, intersecting the main grooves at an angle of 30°, but not erasing them. These two systems of striations indicate a change in direction of the ice movement, probably near the close of the period of glaciation. At the head of Bonanza Flat the evidence of ice scouring is preserved at many points in smoothed faces of diorite showing distinct scratches (Pl. VIII, *B*) or in fluted mounds of rock. No doubt many glacial markings have been destroyed by the elements, which cause diorite to weather and flake off in convex scales. On more resistant materials, however, such as quartzite, the scouring action of ice is shown in polished rock faces that glisten in the sunlight. The best instance is the quartzite knob in the valley north of Lone Hill. Striations of a glacial character but on loose rock fragments were seen in Thaynes, Empire, and Whitepine canyons.

Other phenomena commonly attributed to ice action are the oval knolls of bedrock, roches moutonnées, at the heads of Thaynes, Big Cottonwood, and Bonanza canyons and on the western slope of Clayton Peak. The roches moutonnées, however, have been so much broken by



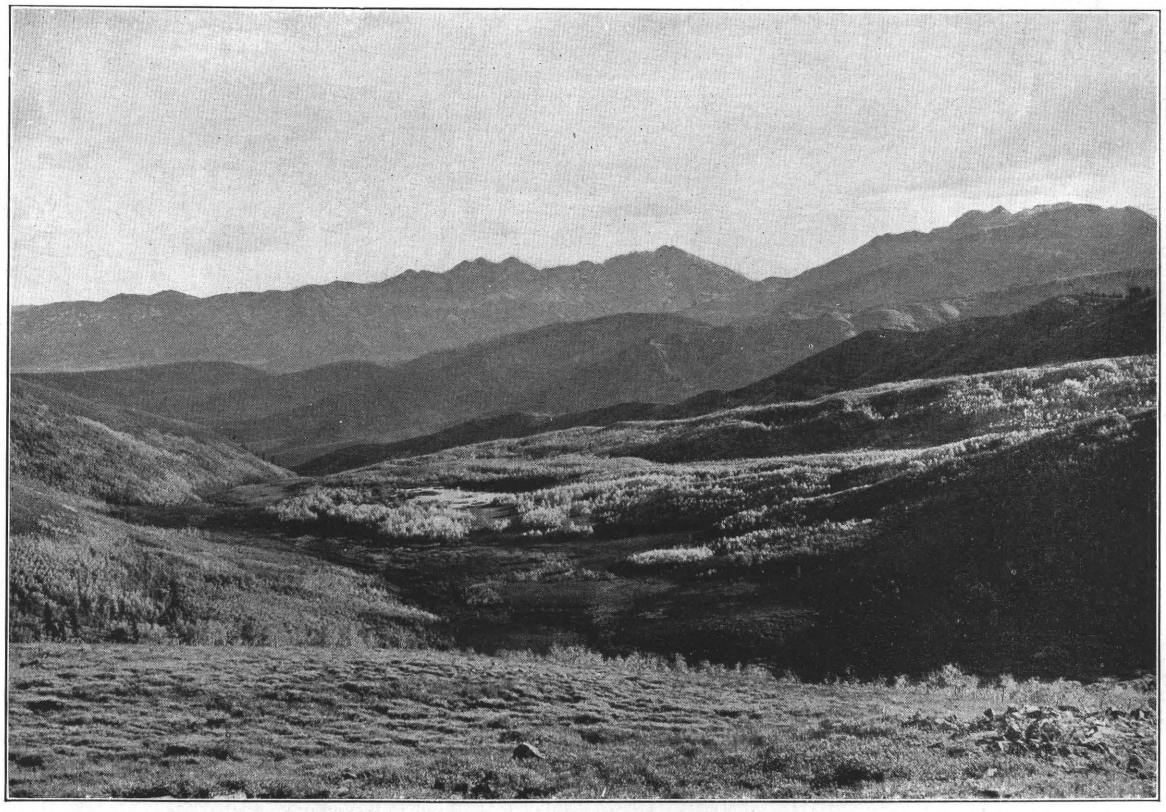
A. GLACIATED CANYON.

U-shaped profile and amphitheaters at head of Thaynes Canyon. Looking south.

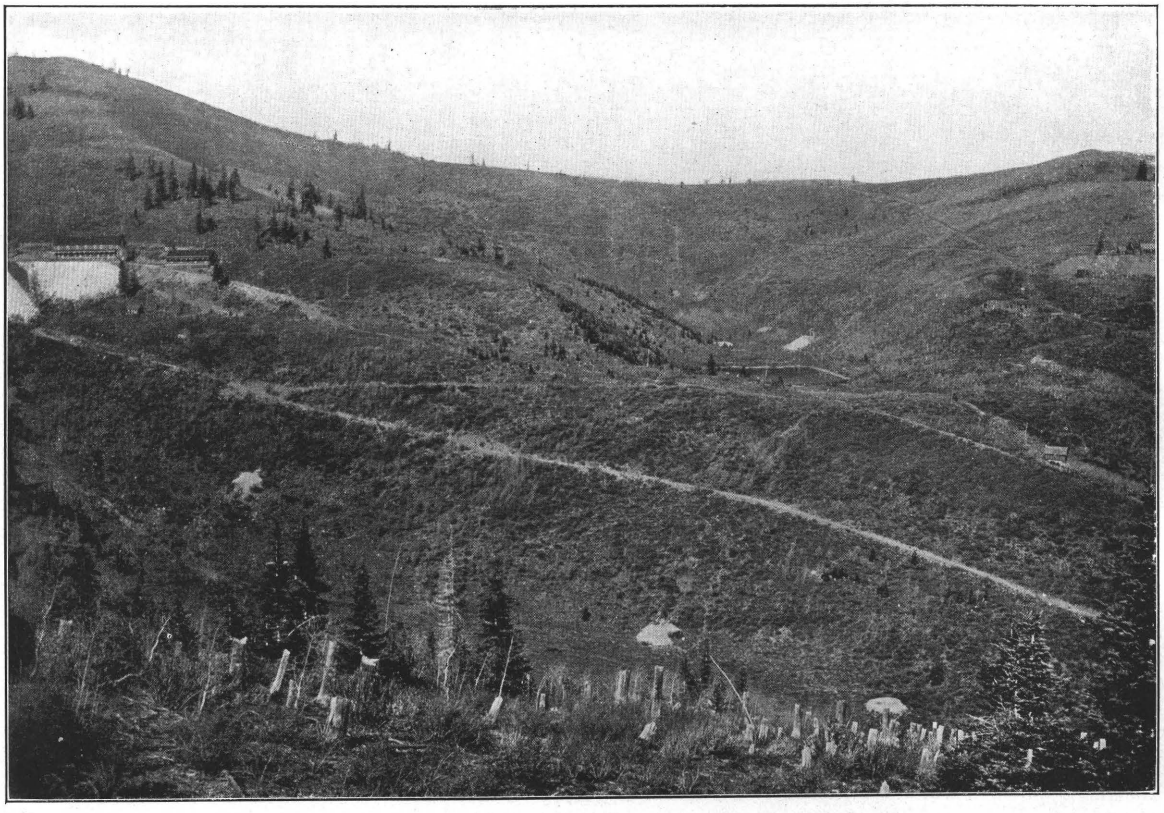
B. GLACIAL STRIÆ.

On roches moutonnées of diorite, eastern slope of Clayton Peak, in upper Bonanza Flat.

GLACIAL EROSION.



A. PONDING BY GROUND AND FRONTAL MORAINES AT EAST END OF BONANZA FLAT.
Looking southwest, toward main divide of Wasatch Range. In background Timpanogos Peak and (at left) Provo Peaks.



B. LATERAL MORAINE PONDING LADY MORGAN LAKES.
Looking northwest. Daly-Judge office and bunk house at left.

MORAINES DAMMING GLACIAL LAKES.

weathering into rough forms, that, while close inspection reveals ice-worn surfaces, the effect of the whole is best gathered from a distant viewpoint. (See Pl. IV, *B*, p. 44.)

Other evidence of glaciation consists in the deposits of fragmental rock found in all the canyons. These deposits blanket the entire floor of each canyon, except a portion of Whitepine and the lower part of Empire. The gravel blankets extend into the extreme heads of all the canyons, except Thaynes and Bonanza and perhaps some canyons on the western slope, and merge into deposits which are not deemed to be glacial, but rather to have resulted from recent landslides and accumulations on snow banks. Deposits with a short vertical range occur also on the valley slopes. Thus Empire Canyon displays loose deposits near the lakes west of the Daly West mine, about Daly No. 2 shaft, opposite the outlet of Walker & Webster Gulch, and on the elongated lateral ridges above Park City. In Thaynes and Bonanza canyons slightly elevated deposits were observed on the north sides near the gaps into Big Cottonwood Canyon. In Bonanza Canyon these deposits appear to cover a rock shelf whose edge protrudes in places. In the lower courses of Thaynes and Bonanza canyons high-lying gravels were seen. Thus the lateral ridge which diverts Bogan Creek on the south side of Thaynes Canyon and the ridges on the southwest side of Bonanza Flat near the boundary of the area mapped are covered with morainal material, and the summit of Lone Hill displays many perched bowlders of diorite evidently plucked from the Clayton Peak mass by the glacier and dropped on Lone Hill when the ice melted. Moraines damming glacial lakes are shown in Plate IX. The spur east of Ontario Canyon also exhibits small patches of rounded gravels near the Constellation mine; in fact, the shaft of this mine penetrates such a deposit to a depth of 100 feet. Moreover, the long, low ridges bordering the mouth of Empire Canyon are more or less covered with glacial materials for a considerable distance, as shown on Plate XXXIX (p. 132). The two occurrences last named may not have been ice-laid gravels, but outwash gravels. If the latter, then they would form a tie between the great blanket of outwash gravels on the eastern slope and the glacial deposits in the canyons to the west, and perhaps establish the contemporaneity of these two classes of deposits.

The accumulations of presumably glacial materials in the lower courses of the valleys are commonly smooth or rolling; those higher up are characterized by ridges trending parallel with the valley; and finally, the accumulations near the valley heads, probably in part composed of landslide material, have, especially in the valleys of the northern slope, a distinctly kame and kettle surface. In places small lakes occupy the depressions.

All the deposits in the canyons seem to be derived only from the rocks that surround the canyons; hence some of these deposits are very similar in composition. In character also they are much alike, for the gravels are generally not much rounded and not of striking difference in size, especially in the lower and middle parts of the valleys. Nevertheless, Thaynes Canyon and Bonanza Flat display some large bowlders mixed with the fine débris, and in the middle portion of Whitepine Canyon, protruding from the fine material, are half a dozen huge blocks of argillaceous limestone. Some of the fragmental débris, especially the limestones and shales, still preserves evidences of glaciation in polished surfaces and striations.

Nowhere was the glacial material exposed in section, hence variations between top and bottom due to sorting were not made out. For the same reason no stratification was seen, though in some places in the lower parts of the valleys it no doubt exists. The material nearer the heads of the valleys, on the contrary, has every appearance of ordinary till. As bedrock was reached in only a few abandoned shafts and prospects, little detail can be given as to the thickness of the material at various points. It is probably thickest toward the valley heads, becoming thinner downstream. The thicker parts are probably no less than 50 feet thick and perhaps very much more; for even in the lower part of Thaynes Canyon the morainal ridge on the east side is 20 to 30 feet thick, and on Bonanza Flat prospect holes show 20 feet of glacial débris.

Beneath such deposits as are above described the bedrock geology can not be fully made out in all places. In Whitepine Canyon, however, the Thaynes and Ankareh formations evidently underlie the glacial deposits and their contact may be approximately determined. The eastern

outline of the main igneous body in Brighton Gap is believed to be approximately coincident with the edge of the drift. As geologic details of its locality are given in the description of each mine, it is sufficient here to generalize. The Park City formation probably underlies the glacial spur of Daly No. 2 shaft and steps northwestward on a complicated system of faulting across the Massachusetts spur to the Silver King area. To the south the formation issues from beneath the drift near the Quincy mine. The extent of the Woodside shale is very similar. The shale area west of Quincy shaft is probably connected beneath the drift with that north of the Daly West mine, except where invaded by the porphyry dike. Thence, skirting the western slope of the canyon the shale disappears beneath the Walker & Webster drift cap and after suffering much faulting and crumpling seems to join the Silver King shale area to the north. The Thaynes formation, which possibly is cut by strong fissures and a few small dikes at the head of Empire Canyon, is largely covered with drift at that point but emerges and rounds the spur to the north and traverses Walker & Webster Gulch underneath the drift tongue. The Ankareh shale, which forms the southern cirques of Walker & Webster Gulch, extends underneath the deposits of the northern cirque also. At this point it is cut off by a fault, and the Thaynes formation forms the bedrock bottom of the drift from this locality northward. The Bonanza drift sheet laps on the north and east against metamorphosed beds which range from the Thaynes formation to the Weber quartzite, and on the west against the great diorite stock of Clayton Peak. Hence the upper portion of the drift cap probably covers the main irregular contact between the sediments and the diorite, and the lower part overlies Weber quartzite and many intrusions of diorite porphyry. The remaining canyons south of Clayton Peak lie largely in sediments, though heading in the diorite mass.

From the facts above stated it may perhaps be safely concluded that ice fields, thick at the source and thinning outward, but probably nowhere except in Empire Canyon thick enough to reach the valley rim, lay in the canyons of the western half of the Park City district and for the most part extended beyond the border of the area mapped. In Bonanza Flat the ice probably covered Lone Hill, and in Thaynes Canyon it seems to have reached at least the height of the morainal ridge which caused the diversion of Bogan Creek. In Empire Canyon, however, it probably filled the lower course, blocking the mouth of Woodside Gulch and causing Woodside Creek to cut a new channel, which it has followed to the present time. That Ontario Creek was diverted in a similar manner seems probable from its analogous position, but little or no evidence of this remains to-day, and glacial deposits on the outer slopes of either valley are not recognizable beyond doubt.

During the glacial epoch snow no doubt covered the eastern slope of the district, but apparently not in sufficient quantity to produce ice bodies of significant size in any of the drainage basins, although the floods resulting from the melting of this snow might easily have caused great outwash fans. A discussion of these deposits may well precede a consideration of postglacial erosion.

SEDIMENTS.

Though some of the downstream parts of the deposits described as glacial may have been waterlaid, they are not certainly distinguishable as such within the area mapped. The present heading refers more particularly to certain high-lying gravels common to the eastern slope, where no other evidence of the glacial epoch was observed. These gravels blanket the low flat country which skirts the eastern slope of the Park City district and extends eastward to the West Hills. The extent of the gravel blanket is not definitely known, and only the arms and outliers which come within the area mapped were studied in detail.

Within the district under discussion the high gravels occur in two localities—a large northern area extending from Big Dutch Pete Hollow to Drain Tunnel Creek, and a small southern area located near the point where the boundary of the area mapped crosses Cottonwood Canyon. The southern area lies on the west flank of Cottonwood Canyon and reaches an elevation of 6,500 feet. There are small remnants on the opposite slope of the canyon directly east of the Valeo mine and on the south rim of Dutch Hollow, lying between 7,000 and 7,300 feet high. The northern gravel blanket lies mainly below 6,500 feet, with arms extending up to 6,800 feet, but on the

spur between Glencoe and McHenry canyons it reaches nearly to 7,500 feet, and on the lateral spur to the northwest a few scattered patches occur above 7,000 feet.

At the higher elevations the gravels usually occur as patches on the crests of ridges and the faces of truncated spurs, but in the lower country they take the form of long arms, which broaden out to the east until they cover valleys and low ridges alike.

These deposits everywhere present a smooth, even surface in strong contrast to the hilly topography of some ice-laid deposits. Their material consists chiefly of rock fragments from the slopes and hills on the west, and consequently varies, roughly speaking, with the position of the deposits. Thus, in the northern part of the larger gravel area, fragments of andesite, sandstone, and limestone predominate, whereas in the southern portion of the same area these rocks are replaced largely by porphyry and quartzite. In the southern gravel area the fragments are mainly quartzite with some porphyry.

Aside from extent, topography, or composition the character of the deposits seems conclusive as to their history. The pebbles are waterworn, those in the lower stretches being more rounded than those on the ridges. In size there is wide divergence, the material ranging from sand to bowlders several inches in diameter. Surface indications showed nothing as to the sorting of the material, but sections exposed at the overflow of the Ontario drain tunnel and along irrigating ditches north of this point displayed excellent stratification, bands of sand being intercalated with layers of gravel and bowlders. No cross-bedding and no special differences between the top and bottom of the sections were observed. No section of the southern gravel area was seen.

Very little can be said as to the thickness of the gravel deposits. They naturally become attenuated on the edges and probably thicken toward the river on the east. The sections noted above were the only ones available for measurement, and these gave a thickness of 30 to 50 feet.

To judge from the outcrops that have been uncovered by stream action or protrude from the gravel blanket, andesitic lava seems to be the most prevalent underlying rock. The western edge of the northern area, however, lies upon Weber quartzite and in places upon porphyry. The rocks underneath the southern gravel sheet are not so certain. Its eastern edge probably covers some andesite and thence westward it lies upon the formations not hidden by the andesite itself, possibly a small corner of the Thaynes near the bottom of Cottonwood Canyon and perhaps portions of the Woodside and Park City formations.

The above description of the gravel sheets gives some clue to their history. The rounded shapes of the pebbles and their stratified occurrence indicate that they were laid down by water in their present position. To cover so extensive an area with gravels to a thickness probably much over 50 feet requires deposition during a considerable period of time, depending among other things on the volume and velocity of the water. That the strength of the current fluctuated considerably is shown by the interbedded layers of bowlders and sand. This may be explained by changes in amount of rainfall or in the rate of melting of snow. It seems most natural, therefore, to refer the deposition of these gravels to a time of great precipitation, and as the only such time certainly known in this region is that of the glacial period these gravels may be considered as contemporaneous with the ice-laid deposits of the region. As already stated, this correlation is supported by the occurrence of rounded gravels near the Constellation mine and at the mouths of Deer Valley and Empire Canyon, which merge the gravel blanket on the east with the glacial deposits on the west. This conclusion naturally raises the question why there was glaciation in the western part of the district and not in the eastern part, lying only a few miles distant and having practically the same physical characters. In answer to this question it may be stated that glaciation apparently became less vigorous eastward. Ontario Canyon shows slight but questionable evidence of a small ice patch and, to judge from the deposits, the ice tongues in Empire Canyon and Walker & Webster Gulch were at best small compared with those in Bonanza and Little Cottonwood canyons. Hence it seems probable that the snows on the eastern slope were insufficient to consolidate into ice, though they sufficed to furnish a large

supply of water. Perhaps the prevailing storms of that period struck the Wasatch Range from the west and most of the precipitation was done before they crossed the summit.

Erosion since these gravels were deposited has been considerable, as is shown by the valleys which have incised not only the gravel blanket but some of the bedrock as well. McCune Hollow is a good example; no doubt the deposits on either slope were formerly connected in one nearly smooth plain. Since that time, which was probably at the close of the glacial epoch, McCune Hollow has been cut through the gravel blanket down to bedrock. Postglacial erosion elsewhere in the district is not so clearly shown. Perhaps the lower course of Woodside Gulch has been considerably deepened, probably somewhat less than the vertical distance between the stream and the crest of the low glacial ridge on the east, and Bogan Creek appears to have cut about 20 feet into bedrock below the morainal deposits on its west side.

LANDSLIDES.

Since the field work in the Park City district was finished, the writer has visited the San Juan Mountains of Colorado and studied the Quaternary deposits of that region. Many of these deposits are undoubtedly composed of landslide or "rock stream" material, which in many respects appears identical with that of deposits accepted as glacial. These deposits occur chiefly at the heads of cirques, contain domestic rocks only, and exhibit no striations. Their striking similarity to certain accumulations in the Park City district has led the writer to describe the latter under this heading.[1]

Such deposits were noted in several of the cirques of the district, particularly those about Clayton Peak and those east of Jupiter and Scott hills. In fact, Thaynes and Empire canyons are the only prominent valleys without these deposits. At the very heads of the cirques named lie heaps of rock fragments forming conical hills or funnel-shaped basins. In some cirques disintegration of the material has gone far enough to furnish a foothold for minor vegetation, though rarely for trees, but in other places the material has still the bare aspect of fresh accumulations. The latter appearance is particularly common in the diorite area about Clayton Peak; the former is best shown in areas of sedimentary rock, as at the heads of Whitepine Canyon, and Walker & Webster Gulch and southeast of Clayton Peak. In the latter localities many of the accumulations are highest near the middle of the cirque. In the diorite area, where the material is coarser, the conspicuous feature consists of marginal ridges following the limbs of the cirque and having a ditch on either side. The outer side of the outer ditch is commonly formed by talus from the wall of the cirque and the inner bank of the inner ditch, where there are two ditches, is formed by the mass of loose material that lies on the bottom of the cirque. In places, however, this material is not sufficient to form a ditch with the marginal débris. The central mass may be of large or small extent, and though there are cirques where great grassy hollows occur in the mass it is generally smoother than the corresponding hilly deposits in areas of sedimentary rocks. At one point in the gulch on the southern border of the district just west of longitude 111° 32′ the marginal ridges are joined in the middle of the gulch bottom, forming a high buttress transverse to the valley and inclosing minor rows of rock in a roughly concentric arrangement. The height of these ridges ranges up to 50 feet, though the extreme relief may be somewhat greater. The concentric arrangement is a characteristic of the "rock streams" which abound in the San Juan Mountains.

The débris composing these deposits is derived from the rocks forming the walls of the cirques. There is very little, if any mixing, and many of the fragments appear to have been freshly chipped from the same mass. The sedimentary material is very angular as if recently broken down nearly in place, although the igneous fragments may have their edges slightly beveled, as if by ordinary weathering. No striations on the fragments were observed. In the sedimentary areas the pieces were generally rather small, or at least there was much fine material among the coarse, whereas in the igneous areas the pieces averaged very large, frequently reaching 10 feet each way. These huge blocks mixed with smaller ones were piled up to a

[1] For a discussion of this class of Quaternary deposits see Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.

height of 50 feet or thereabouts, and so loosely that a man could stand in the cracks and would find difficulty in traversing the surface.

It may be noted here that ordinary rock slips appear to have occurred on the sides of two or three canyons. Thus the benches just below Shadow Lake in Thaynes Canyon and beneath Jupiter Hill in Bonanza Canyon may perhaps be due to surficial dislocations of large masses of strata. But their topographic features are not like the forms just discussed, and their landslide character is merely a possibility.

As much of the above description might be applied to glacial material little can be definitely concluded from it alone. The fact, however, that the deposits are generally highest in the middle of the cirques might seem unusual for accumulations due to glaciers. Comparison with similar types of accumulation in the San Juan Mountains enables the best conclusions to be drawn. All the forms of deposits in the Park City area may be duplicated in the San Juan Mountains by deposits which can not well be explained by the glacial theory only. The San Juan deposits are, in fact, thought to be due to immense slides of massive rock which has disintegrated in places subsequent to the slide. This explanation may be applied in the Park City district to the hill and basin deposits at the heads of cirques in the area of sedimentary rocks. After disintegration the resulting mass of fragments may undergo movement on the rock bed, resulting in a rough concentric arrangement about the lower edge of the mass and in lateral ridges and ditches where it has broken away on the sides. This possibly accounts for the marginal ridges and trenches in some of the cirques about Clayton Peak. Some of the slides may have overridden residual snow or ice banks or may have come out upon the ice during the glacial epoch and received some of their topographic features from that agent. In short, these indeterminate deposits are difficult of adequate explanation in the light of the present knowledge of landslide phenomena in the Wasatch Mountains. It is believed that they are not due to glaciation alone, and that they may have been formed later than the glacial epoch. The normal landslips near the Brighton gaps at the heads of Thaynes and Bonanza canyons need no special explanation.

ALLUVIUM.

Accumulations of material by recent streams appear only at wide intervals in this region. They include some of the meadows in the glacial basins of Bonanza Flat, flood plains along Cottonwood and Drain Tunnel creeks, and the pasture bottom of Deer Valley. Being of little economic or geologic importance they merit no further attention.

IGNEOUS ROCKS.

GENERAL FEATURES.

The Park City district lies in the great zone of eruption of eastern and northern Utah. This zone is marked by the monzonite eruptives of the Bingham district, in the Oquirrh Range; by the porphyritic granite close to the mouth of Little Cottonwood Canyon, the granodiorite near Alta, and the diorite masses of the Park City region, in the Wasatch Range; and by andesite flows on the east between the Wasatch and Uinta ranges. The general outlines of these several masses were determined by the pioneer geologists on the early surveys,[1] additional features have been observed during recent reconnaissances,[2] and the two limiting areas—the Bingham[3] and Park City mining districts—have been studied in detail.

These intrusive rocks extend in an east-west chain entirely across the central Wasatch. Between the above-mentioned limiting masses three extensive irregular bodies have been recognized and their general geologic features and relationship have been determined. Deep, narrow canyons have been incised in them by Little and Big Cottonwood creeks on the western slope and by Snake Creek, a tributary of Provo River, on the eastern slope, affording excellent

[1] King, Clarence, Emmons, S. F., and Hague, Arnold, U. S. Geol. Expl. 40th Par., 1870–1878.

[2] Emmons, S. F., The Little Cottonwood granite body of the Wasatch Mountains: Am. Jour. Sci., 4th ser., vol. 16, 1903, pp. 139–147. Boutwell, J. M., Progress report on the Park City mining district, Utah: Bull. U. S. Geol. Survey No. 213, 1903, pp. 31–40.

[3] Boutwell, J. M., Keith, Arthur, and Emmons, S. F., Economic geology of the Bingham mining district, Utah: Prof. Paper U. S. Geol. Survey No. 38, 1905.

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exposures. In Little Cottonwood Canyon, about a mile east of the western base of the range, coarse porphyritic granite appears, rising steeply in contact with metamorphic schists. It forms both walls of the canyon for a distance of about 6 miles, making with the Cambrian quartzite of Twin Peaks an irregular contact which crosses the canyon about a mile and a half west of Alta. South of the canyon it forms the entire body of Lone Peak and descends the northern wall into American Fork Canyon.

The second or middle body is made up of a granular, more basic rock of a diorite facies. It outcrops barely a quarter of a mile southeast from Alta post office and stretches thence southward, flooring the great amphitheater at the southern head of Little Cottonwood Canyon; also eastward into Big Cottonwood Canyon, being seen along both the Twin Lake trail and the Lake Catherine Pass farther south, and extending thence southeastward into the head of Snake Creek canyon.

Adjoining this on the east is the third mass, which is granular, fine grained, and more basic, and which proves on microscopic and chemical study to be diorite. It outcrops on the precipitous walls about the extreme southern head of Big Cottonwood Canyon close under Pioneer Peak and extends through the divide into the head of Snake Creek Canyon, but the main mass, stretching eastward and northeastward, forms the eastern rim of the Big Cottonwood amphitheater, also Clayton Peak (Pl. IV, *B*, p. 44), and thence continues eastward across the North Fork of Snake Creek and Bonanza Flat, and northeastward into the main Park City district.

The geologic character of these extensive igneous bodies long remained a mooted question. The geologists of the Fortieth Parallel Survey recognized in the determination of the character of the igneous masses one of the fundamental problems of their work. King saw the close lithologic resemblance between these rocks and some in California which Whitney considered intrusive. But at that time a granitic intrusive was a geologic conception not yet established. Accordingly in their final statement, although realizing that no true basal conglomerate had been found, the Fortieth Parallel geologists held that these igneous masses were Archean.

In 1880 Geikie paid a short visit to the region with this problem in mind and subsequently he published his interpretation of his observations. He gave reasons for dissenting from the conclusions of the geologists of the Fortieth Parallel Survey and described the features which led him to regard these masses as intrusive.

During the summer and fall of 1900, while engaged in a study of the Bingham mining district, the writer made three trips into the Wasatch at the suggestion of Mr. S. F. Emmons. One of these trips was undertaken to secure evidence which would conclusively establish the relation of the igneous to the sedimentary rocks.

In the high spur east-southeast from Alta, between the Twin Lake and Catherine Lake trails, quartzite, schist, and limestone were found in a highly metamorphosed condition underlain and abruptly truncated on the north and south—in short, partly engulfed—by the middle igneous mass. The sediments are also penetrated by a network of dikes and sills, both large and small, near which such characteristic contact minerals as chrome garnet (uvarovite), calcium garnet (grossularite), iron garnet (almandite), magnetite, secondary mica, epidote, and coarsely crystalline marble occur in abundance. Similarly the limestones of Emma Hill, north and northeast of Alta, are highly marbleized as a whole, and along or near the Twin Lake trail they are raggedly truncated by the igneous mass, intruded by tongues and stringers, and intensely metamorphosed. This mass is thus proved to be intrusive.

The northern wall of the Little Cottonwood Canyon from a point about 2 miles below Alta to the contact of the westernmost mass of granite with the overlying Cambrian quartzite showed rectangular masses 25 feet square and dikes of granite extending upward into the quartzite; also sills of granite making off laterally from some of these dikes roughly along the bedding of the quartzite. The intrusive character of this western mass was thus established. The third or easternmost of these bodies, which culminates in Clayton Peak, on detailed study in connection with the examination of the Park City district afforded data indicating unquestionably its intrusive nature.

Two years later the contact of the main Little Cottonwood mass along Gad Valley was studied. Here, too, dikes were found cutting the overlying quartzite, and it was observed that this granite cuts upward progressively from west to east to a horizon within about 2,000 feet of the top of the Cambrian, or through about 10,000 feet of massive quartzite.

It thus appears that the Little Cottonwood mass has been intruded through the pre-Cambrian metamorphic rocks at the mouth of the canyon, tilting them up steeply, has broken upward to the east through a thickness of about 10,000 feet of Cambrian quartzite, and has given off dikes, sills, and apophyses into these sediments. The Alta mass has made its way up through Paleozoic rocks overlying the Cambrian at the head of the canyon, cutting across Carboniferous limestone, which it has metamorphosed highly, and extends eastward to form the western wall about the head of Big Cottonwood Canyon, probably inducing the formation in the abutting truncated limestones of contact-metamorphic minerals and ore deposits. The Clayton mass, lying in juxtaposition with the Alta mass on the west, cuts eastward and upward across Mesozoic formations and highly metamorphoses them.

These several intrusive masses constitute a composite laccolithic or stocklike mass from which the sediments dip away quaquaversally. But whether the three component bodies are distinct in position and age has not yet been positively determined. The Cottonwood mass has not been observed to be physically connected with the Alta mass. The point where these two bodies most closely approach is in the bottom of the main Little Cottonwood Canyon, where a distance of only $1\frac{3}{4}$ miles intervenes between their outcrops.

The evidence on the relation between the Alta mass and the Clayton mass is even less complete. Petrographically these two masses are distinct, the Alta mass being a granodiorite closely resembling those of the Sierra Nevada and the Clayton mass being a normal diorite, but search for conclusive field evidence as to their relation has not met with success.

Concerning the geologic date of the intrusion, the best evidence is afforded by the latest sediments. The quartzite inclosing the Little Cottonwood mass has not yielded fossils in this canyon, but in Big Cottonwood Canyon, immediately north, the quartzite to a thickness of 12,000 feet was measured and determined by Walcott as Lower and Middle Cambrian. The quartzites entered by the Little Cottonwood intrusive mass may safely be correlated with these and accordingly the intrusive mass is at least as late as Middle Cambrian. The Alta mass truncates Carboniferous limestone and probably much later beds, and the Clayton Peak stock cuts sediments of Triassic age.

As to the mode of intrusion, the highly tilted position of the metamorphic rock at the mouth of Little Cottonwood Canyon and the attitude of the mass to the structure of the overlying quartzite along the north side of the canyon suggest that the magma rose on the west and broke upward progressively eastward. Similarly the Alta mass apparently underlay the sediments formerly occupying the south fork of Little Cottonwood Creek and, breaking upward beneath the limestone of Mount Wolverine, rose progressively higher as it moved eastward. In like manner the attitude of the Clayton Peak intrusive mass and of the porphyries in the sediments suggests entrance from the west and progressive movement eastward until the climax was attained in the extensive extrusion of andesites between the Wasatch and Uinta ranges.

DISTRIBUTION AND OCCURRENCE.

TYPES AND PRINCIPAL CHARACTERISTICS.

Igneous rocks occupy nearly one-third of the area of the Park City district. In distribution they coincide in general with the productive area and in occurrence they are intimately associated with ore bodies. The three petrographic types (diorite, diorite porphyry, and andesite) occur in distinct areas.

The diorite forms the most rugged and precipitous ridges and the loftiest summit—Clayton Peak—in the region. The generally homogeneous character of the rock, the absence of dominating structure planes, and the presence of readily removed mineral constituents have combined to permit deep and characteristic dissection. Deep, rounded, steep-sided valleys heading

in broad circular amphitheaters walled in by bare precipitous ledges are representative of the topography developed on this rock. As a rule these valleys have a sparse vegetation of thin grass patches on their lower slopes and evergreens and alpine growth along the higher divides. Good water abounds and the rock basins in the cirques are filled with it the year round. The eastern margin of this mass, with the single exception of an arm in the gap above the head of the Daly Judge shaft, is covered by the extensive glacial deposits of Bonanza Flat.

Rising from beneath this covering on the east and northeast are extensive irregular masses of coarse diorite porphyry. These stretch eastward and northeastward around Bald Mountain in the form of dikes and small stocks for a distance of nearly 4 miles. This rock weathers somewhat easily and forms broad flaring saddles or gaps on divides, as at the head of Empire Canyon near the Lucky Bill shaft and east of the Little Bell shaft on the northern slope descending from Flagstaff Mountain. On the southwestern slope of Bald Mountain it yields a coarse, loose sandy soil which does not encourage the growth of vegetation except scanty grasses and scrubby aspens.

Immediately northeast, also on the extreme southeast, and lying about the eastern foothills of the range are parts of the great extrusive mass of andesite which floors the valley between the Wasatch and Uinta ranges. The surface of that portion of the extrusive mass which appears within the Park City area slopes gently eastward away from the Wasatch and is cut by numerous shallow gullies into parallel strips. In these small areas, however, the characteristic topography shown in the rugged hills farther east is imperfectly attained.

DIORITE.

The diorite occurs in a general oval area, which extends from the head of Big Cottonwood Canyon eastward in the upper basin of Snake Creek a distance of over 3 miles and from the head of Snake Creek northward, where it forms the main divide of the Wasatch for a distance of 2 miles. Its location is thus in the main zone of intrusive rocks of the middle Wasatch, being the easternmost of three great igneous masses, and in the Park City district it occupies the southwestern portion. It cuts across sediments at the heads of various northwest tributaries of Snake Creek, also those at the head of Big Cottonwood, and is buried on the east by the glacial deposits of Bonanza Flat. The only occurrences farther east are the broad tongue on which the gap above the Daly-Judge tunnel is located, and small portions of its contact along the main road in Bonanza Flat immediately east. The best exposures were found along its northern and southern contacts.

The sediments on the south side are abruptly truncated along a generally straight course. As may be read from the geologic map (Pl. II, p. 44), this contact crosses canyons and ridges with little or no deviation from its course and accordingly may be regarded as a practically vertical plane. The principal irregularity found in this contact was at the head of the gulch next east of the southern tier, where there are lenticular horses of quartzite and limestone and jagged contacts between sediments and diorite.

On the north side the contact is much more irregular and is exposed in prospects at several points. On the south slope of the triangular peak at the head of Thaynes Canyon and southwest of Jupiter Hill the diorite breaks up through altered limestone in forking tongues. In the northern face of this peak near its base the diorite again irregularly penetrates the sediments from below and appears to have extended to this point from the main body on the south, under the beds now forming this ridge. In the low knob immediately west of the swampy area at the base of this peak in Bonanza Flat the metamorphosed marble is banded with sills and irregular tongues of diorite. Again, immediately west of the Jones shaft, in the east end of the low spur that ends at this point diorite passes through brown limestone in irregular narrow apophyses with thin branching sills, as indicated in figure 4 (p. 99). Immediately east, just at the nose of the spur, an excavation beside the road reveals an upper contact of a knoblike intrusive of diorite cutting brecciated limestone and sandstone. (See fig. 3, p. 97.) In considering the form of this Clayton Peak mass its proved thickness of at least 2,000 feet is to be noted.

From these features it seems that the diorite of Clayton Peak is a stock, that it broke upward almost vertically on the south and toward higher horizons on the north and east, deforming the overlying sediments and sending irregular dikes and sills into them.

DIORITE PORPHYRY.

This porphyry is the largest and most widely extended of the igneous formations within this area. It lies mainly in the eastern and southern parts of the district, but a few small isolated bodies occur at the west and northeast. All the large areas and nearly all the exposures appear to be united on the surface into a single extremely irregular body which is roughly separated by the quartzite on Bald Mountain, except for a narrow junction on the east, into two parallel masses. The southern and major member extends from the extreme head of Empire Canyon in the region of the Daly-Judge, Daly West, Quincy, and Little Bell mines eastward and southeastward to its junction with the northern mass east of the Valeo mine, in Cottonwood Canyon. It is well exposed by the broad, shallow amphitheater and saddle at the south head of Empire Canyon and is characteristically developed in the main bodies which extend eastward and southward, in the irregular connecting dikes around the eastern wall of Bonanza Flat, and about the heads of Durey and Pine canyons. From the connecting neck in Cottonwood Canyon the northern mass extends northward and northeastward around Bald Mountain, crossing Glencoe, Wasatch, and McHenry gulches, and an arm reaching northward enters McCune Hollow. Owing to the exceeding difficulty of tracing outlines on precipitous slopes amid dense scrubby growth the boundaries above given necessarily fall far short of showing the extremely irregular outlines of these masses.

The major part of this porphyry takes the form of irregular stocks and dikes issuing from the stocks. A few sills are present. The principal stocks are the elongated, roughly rectangular masses immediately south of Bald Mountain and that east and northeast of the same locality. Smaller masses lie at the head of Empire Canyon and between Bald and Bald Eagle mountains.

The extent of these bodies in depth is of the greatest practical importance in mining. Thus when this survey was begun the opinion prevailed among some of the best mining men in the camp that the igneous rock composing Clayton Peak was a flat body (a sill) and that ore-bearing limestones underlay it which could be tapped by sinking. Critical geologic study has proved, however, that this view is not tenable and that the diorite descends almost vertically far beyond minable limits. In connection with the porphyry bodies similar practical questions have arisen. Thus the form of the Lucky Bill body determines the position and extent of adjoining ore-bearing limestone. The surface form and depth of dissection of this body strongly suggest that it is not a sill but is a broad dike or a stock which descends deep.

The typical dikes of this region vary exceedingly in both width and trend, and the contacts or walls of those best exposed stand nearly vertical. This is shown by the dike exposed on the west side of the amphitheater occupied by Lady Morgan Lakes, by those ascending the eastern wall of Bonanza Flat, and by excellent examples in the Daly West, Daly-Judge, and Comstock mines.

ANDESITE.

The two small portions of the great extrusive mass of andesite on the east included within this area afford good evidence as to its general characteristics. They lie in the extreme northeast and southeast corners of the region mapped, at the eastern base of the range, and embrace an area barely a mile square. The great expanse of these rocks which stretches eastward about 8 miles to Kamas Prairie and in a northwesterly and southeasterly direction about 30 miles shows high rugged hills rising 1,000 to 2,000 feet above its western margin in the Park City district. If the upper surface of these extrusive masses were originally level, it would follow that the present lower elevations of its western portions, which now wrap about the eastern flanks of the Wasatch, are due to denudation along that margin.

At present the even slopes on the andesite descend gently from the range toward the east. Low gullies cut deeply into the extrusive mass and show it to be made up of layers of varying

density, coarseness, and massiveness. (See Pl. X.) Some were clearly formed as flows, others as beds of bomblike bodies, possibly ejectamenta. It is to be noted that all these beds are now inclined to the east. These features are perhaps best exposed in the face of the domelike knob at the entrance of the gorge which Provo River has cut in the mass.

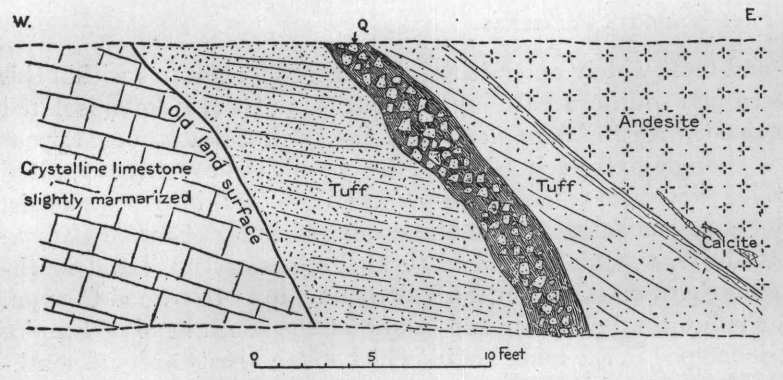


FIGURE 2.—Old land surface of metamorphic limestone overlain by tuff deposits and andesitic flows, the tuff separated by bed of subangular waterworn quartzite pebbles (Q); at northeast corner of Park City district.

In several of the transverse valleys in the West Hills sandstone and quartzite which crop out from beneath their andesitic blanket afford some clue to the topography which preceded the extrusion. Again, the eastern dip from the flanks of the Wasatch and the western dip of certain beds in the eastern part of the area suggest the early valley form, although there is a possibility that the Wasatch has risen since the extrusion and imparted an eastern inclination to the andesite beds (fig. 2). From the evidence it appears that into an early valley between the Uinta and Wasatch ranges a succession of andesite flows was poured out and that they filled it to an unknown great depth.

PETROGRAPHIC DESCRIPTIONS.

ANDESITE.

Definition.—Andesite is a porphyritic extrusive rock whose crystallized minerals are plagioclase and one or more of the three minerals biotite, hornblende, and augite. The uncrystallized part is volcanic glass. In this region the dark minerals are chiefly hornblende and biotite, with rarely some augite. As a whole, andesites are dark-colored rocks of medium grain, usually showing in outcrop various shades of color, depending on the degree of weathering. The recognizable minerals stand out from a finer background and give the rock a porphyritic appearance. Of these minerals the most prominent are crystals of whitish feldspars. The smaller dark laths of hornblende and flakes of mica are less conspicuous. The rock may contain 54 to 68 per cent of silica, 15 to 18 per cent of alumina, rarely more than 6 per cent of iron oxides, seldom more than 4 per cent of magnesia, about 6 per cent of lime, and commonly 5 to 10 per cent of alkalies, soda usually preponderating over potash.

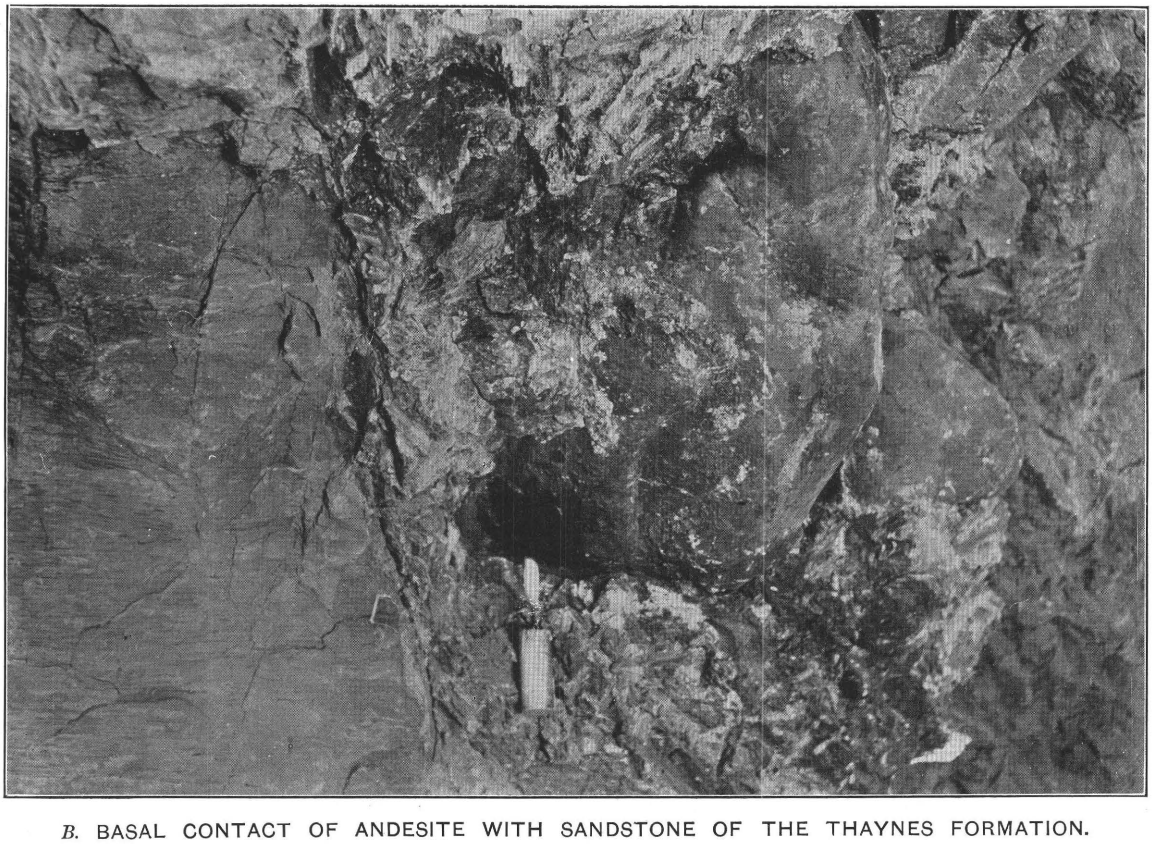
Macroscopic features.—The andesite of this region is a pinkish or greenish rock, commonly gray on fresh fracture, having a decidedly speckled appearance. In hand specimens these colors seem confined to a dense, fine-grained groundmass in which are sprinkled phenocrysts of feldspar, hornblende, and mica (Pl. XI, *A*).

Of the phenocrysts the feldspars seem to predominate, with smaller amounts of hornblende and still less biotite. In places they are arranged in parallel lines significant of rock flowage. Both phenocrysts and groundmass usually lack that lustrous appearance which characterizes a fresh rock. Some of the feldspars, however, have still retained fresh glassy faces on which may be distinguished the multiple twinning lines of plagioclase. The feldspars are the largest of the phenocrysts and vary in size from one-fourth of an inch to small grains. Hornblende crystals are more uniform in size, being as a rule not longer than one-eighth of an inch. Biotite ranges between these two minerals. Rarely a few quartz grains may be recognized. All the phenocrysts grade into the groundmass, which is macroscopically very dense and indeterminate.

The general color of much of the rock is mottled and inspection reveals a corresponding change in texture indicating that the rock is brecciated or composed of fragments in an andesitic matrix. All fragments, however, are found to contain the same essential minerals as the matrix in like proportions, and the whole may be called andesite breccia.

A. BEDDED STRUCTURE IN ANDESITIC FLOWS AND BRECCIAS, NORTH OF MOUTH OF ONTARIO DRAIN TUNNEL.

Looking north.



B. BASAL CONTACT OF ANDESITE WITH SANDSTONE OF THE THAYNES FORMATION.

Exposure along wall of tunnel northeast of Park City district. Water-worn pebbles inclosed at base of tuffaceous material.

STRUCTURE AND RELATIONS OF ANDESITIC FLOWS.

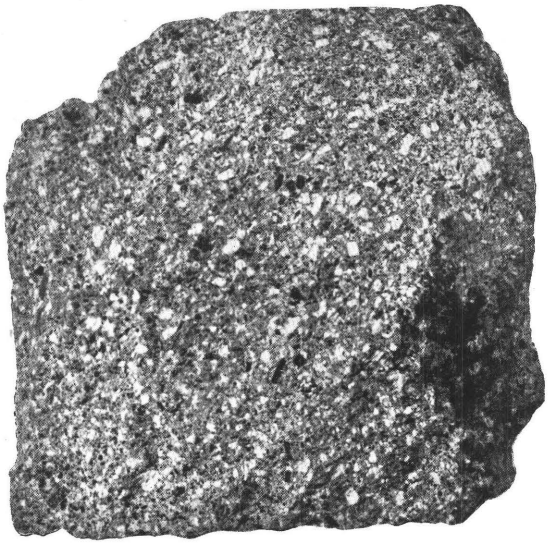
PLATE XI.

PLATE XI.

Andesite.

A. Hand specimen showing a weathered porphyritic gray rock of medium grain bearing phenocrysts of feldspar up to one-eighth inch in size, small hornblendes, and some biotite flakes, in a gray groundmass. Fracture rough. Natural size.

B. Photomicrograph showing phenocrysts of plagioclase (*p*) more abundant than hornblende (*h*), more abundant than biotite (*b*) with some magnetite (*mag*) and pyrite and a very few quartz grains in a groundmass composed of plagioclase microlites and fragments of the phenocrysts in a glassy base. × 35.



A. HAND SPECIMEN.

B. PHOTOMICROGRAPH.

ANDESITE.

In the andesite area were found three rocks showing distinct macroscopic variations. Two of these vary from the normal andesite in being less prominently porphyritic, dense, fine-grained rocks; one (P. U. 435) is whitish and carries distinct small phenocrysts of a dark mineral; the other (P. U. 433) is brown and contains a few small crystals of hornblende and minute laths of feldspar. A third rock (P. U. 410) is much more coarsely porphyritic than the andesite. Of its crystallized minerals, many of the plagioclases are one-half inch in length, but the biotite, hornblende, and quartz are considerably smaller. This porphyritic rock may belong to an earlier period of eruption, though it resembles the andesite in mineral composition.

Microscopic features.—Thin sections of typical andesite from this region, examined under the microscope, reveal a medium-grained porphyritic rock. The phenocrysts which are usually less and rarely greater in volume than the groundmass, vary greatly in size, from one-fourth or one-third inch downward, and are in general fairly well formed. (See Pl. XI, *B*.) As a rule some feldspars are broken, angular, or somewhat corroded. In some specimens, as in rocks from the Ontario drain tunnel and the ditch cuts north of Drain Tunnel Creek, the feldspar phenocrysts are considerably crushed. Most of the phenocrysts, especially of the darker minerals, show parallel arrangement or flow structure and considerable alteration. The groundmass generally contains more or less glass but may be holocrystalline, a texture which in some specimens appears to be due partly to devitrification of the glass.

Plagioclase exhibits multiple twinning according to the albite and Carlsbad laws, with extinction angles on twins of the former type ranging from 2° to 18°, rarely reaching 26° and 27°, which indicates that albite-oligoclase plagioclases predominate greatly over labradorite. Multiple twinning also serves to distinguish the plagioclase feldspars from the other light-colored minerals present. Orthoclase is apt to show cleavage or alteration, in which it differs from the grains of quartz. Of the dark minerals hornblende occurs usually in elongated prisms which show the brown color, medium relief, parallel cleavage, strong pleochroism, and 20° extinction that distinguish it from the biotite or any augite present. The diamond-shaped cross sections and similar cleavage differentiate the hornblende. The biotite is of the ordinary brown, pleochroic variety showing the peculiar hair-line cleavage, rippling surface, and parallel extinction.

Alteration is particularly prevalent in the andesite of this region. The Ontario drain tunnel, which penetrates the rock to a great depth, shows that this process has gone on to a considerable distance beneath the surface. The minerals most affected are those of the ferromagnesian class. Hornblende, for instance, where much changed is marked by a rim of the iron oxides, usually magnetite, inclosing calcite and chlorite (or serpentine) and in places some epidote and muscovite. Biotite usually alters to chlorite and one or more of the three minerals, quartz, epidote, and kaolin. In some places the change has gone no farther than to bleach the biotite, so that it resembles muscovite. In others both the biotite and the hornblende are so essentially changed that recognition except by crystal form is difficult. The lime-soda feldspars are less completely decomposed than the ferromagnesian minerals, and the usual change is to calcite, muscovite, and paragonite, with more or less epidote, quartz, and kaolin. Some fractured crystals contain veins of secondary quartz. Finally magnetite, which is generally present, is in places partly hydrated to limonite.

The groundmass, where hyaline, shows more or less turbid glass in which occur microlitic plagioclase and grains of the other phenocrysts. The microlites commonly assume a felty flow structure. By a decrease in the glassy base the groundmass becomes holocrystalline and then it consists of a microscopic feldspar-quartz intergrowth containing scattered grains of the other minerals. Alteration in the groundmass is shown by devitrification of the glass to granular quartz or to quartz and feldspar aggregates. Microscopic examination of the rocks exhibiting marked megascopic variations from the normal andesite shows clearly that the dense brown rock (P. U. 433) is a facies of andesite in which augite replaces the biotite. The light dense rock (P. U. 435) seems also to be a phase of andesite, but it is an acidic phase, for very little hornblende is present and quartz is rather conspicuous. In the coarsely porphyritic rock (P. U. 410) the microscope reveals practically the same mineralogic composition as the andesite, with perhaps slightly more biotite. In this respect it resembles nearly all the dike rocks. As structurally it

most resembles the diorite porphyries and as in age also it seems to differ from the andesite, it is classed with the dike rocks or diorite porphyry.

Chemical composition.—A chemical analysis of the andesite is given below, together with an analysis of a similar andesite from Plumas County, Cal., for comparison.

Analyses of andesites.

[W. F. Hillebrand, analyst.]

	1	2		1	2		1	2
SiO_2	54.23	58.47	H_2O+	3.71	0.92	Cr_2O_3	None.	.....
Al_2O_3	17.37	18.80	TiO_2	.75	.51	NiO	.....	.....
Fe_2O_3	4.00	3.34	ZrO_2	.02	.....	MnO	0.10	0.13
FeO	1.95	2.64	CO_2	.33	.....	BaO	.15	.09
MgO	3.00	2.69	P_2O_5	.34	.22	SrO	.06	.05
CaO	6.67	6.60	SO_3	None.	.....	Li_2O	Faint trace.	Trace.
Na_2O	2.96	3.58	Cl	Trace.	.....		100.06	100.19
K_2O	2.80	2.01	F	(?)	.....			
H_2O-	1.60	.14	FeS_2	.02 (.01S)	.....			

1. Andesite from Ontario drain tunnel, 810 feet from mouth, Park City, Utah.
2. Andesite 4 miles southeast of Pilot Peak, Plumas County, Cal. Turner, H. W., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 619.

The percentage of silica is somewhat low for rocks usually put in this class, but in the proportions of other elements it holds a medial place. From its mode of occurrence, mineralogic character, and chemical composition, therefore, this rock seems to belong with the andesites, or in accordance with a recent more precise classification, to be shoshonose.

ANDESITE TUFF.

Definition and description.—Beds formed of the finer fragmental material derived from explosive eruptions are commonly called tuff; the coarser ejecta form breccia. Tuffs are rarely well stratified, though they may be cemented by percolating waters into firm rocks. In general the lighter varieties, which range in color from whitish to whitish gray, are rhyolitic tuffs, and the darker sorts are the andesitic or more basic types. In chemical composition they range from acidic (rhyolite) on the one hand to the basic (basalt) on the other. Their distinguishing feature, however, is their fragmental character.

Macroscopic features.—The tuffs from the Park City district hold a medial place in the above description. They are gray to yellowish-gray rocks composed of white, yellow, and black particles, in places resembling a poorly compacted fine sandstone, from which they grade into a very soft, flaky, somewhat argillaceous rock containing larger grains. Specimens from the lower parts of the mass are somewhat laminated; but the laminations seem due rather to flowage, as in mud flows, than to water sorting, for the bedding lines are not distinct and the particles vary greatly in size. The rocks have, however, the appearance of rather even fineness, the grains averaging one-fifth of an inch in size and being loosely cemented together. The bright, fresh appearance of a crystallized rock is lacking. The constituent grains are too small to allow definite determination, though from the abundance of whitish and yellowish particles it may be surmised that considerable feldspar and probably quartz are present.

Microscopic features.—On closer study under the microscope the larger broken constituents appear to lie in an indistinct background which resembles that of andesite. They consist chiefly of broken crystals and not of brecciated rock. These particles cover a wide range in size, grading down to the groundmass. All the fragments, whether large or small, present angular, broken outlines and many are crushed. The larger part have the transparent look of unaltered crystals, although a few of their more soluble neighbors are clouded with foreign substances. Such particles and fragments as remain unaltered may be recognized and determined. Thus it is learned that angular quartz fragments abound with perhaps equally abundant brown patches of iron oxides and much less prominent and greatly altered remnants of feldspars. The fresher parts of the feldspars show the multiple bands of the plagioclases, and these seem to become more numerous toward the top of the tuff body. The interstitial space is occupied by an ill-

defined, streaked groundmass which has a prevailing dingy greenish cast. It composes nearly half the rock in the upper portion of the tuff and toward the bottom increases and predominates over the phenocrysts. The groundmass may be described as a more or less crystallized mat with a granular to faintly microlitic stringy texture. This in places grades into olive-green glass which, though apparently devitrified, still retains its viscous appearance. At other points the groundmass appears broken and the cracks invaded with the greenish glass. It is in this phase of the rock that flow structure is most conspicuous, though specimens were seen in which the obscure microlites seemed to assume the parallelism of flow structure.

The rocks being composed of lightly cohesive fragments, and therefore having a porous character, the ground waters have been enabled to percolate through them and attack the component minerals. Consequently, under the microscope the particles show very general decomposition, being here and there wholly replaced by new compounds. Profound hydration, for example, has produced browned spaces of limonite with dark centers, some of which still retain cores of the magnetite from which the hydrous oxide is derived. Some of the brown oxide penetrates even feldspar crystals, being possibly an alteration product from magnetite inclusions in the crystals. Clear, bright spaces in the groundmass mark blebs of transparent quartz, which appear to be unaffected by alteration. The remains of some ferromagnesian mineral may possibly be represented by scattered patches of limonitic material mixed with calcite. The feldspars, however, are seen clearly to become more or less complete masses of calcite possibly bronzed with limonitic stains.

The upper part of the tuff is evidently the fresher part and is more granular to the feel than the lower part of the bed, where decomposition has progressed further, and the rock has become soft, flaky, and somewhat clayey. The difference between the upper and lower portions of the bed, however, arises partly from differences in the size of the particles and in mineral composition.

Chemical composition.—Analyses of altered rocks, such as the tuffs just described, are unsatisfactory, and hence none is here given. The class to which this rock belongs may be judged from the foregoing descriptions. If the feldspars of the altered specimens belong, like those of the fresher ones, to the plagioclases, and if some of the decomposition products also represent ferromagnesian minerals, then the rock would appear to belong with the fragmental andesites of a quartzose variety.

QUARTZ DIORITE.

Definition.—By diorite is usually meant a holocrystalline granitoid rock consisting of plagioclase, hornblende, and biotite. Usually small amounts of quartz and occasionally augite are present in the diorites of the Park City district, which therefore belong with the quartz diorites. They contain between 49 and 65 per cent of silica, seldom more than 18 per cent of alumina, about 7 per cent of iron oxides, within 3 to 9 per cent of lime, 2 to 8 per cent of magnesia, and usually 5 to 8 per cent of alkalies, of which soda preponderates over potash.

Macroscopic features.—Hand specimens show a fine even-grained rock composed of a uniform mixture of light and dark minerals (Pl. XII, *A*). New fractures generally present a bright, fresh appearance. The light minerals are chiefly white feldspar. Some pinkish feldspar is mingled with the white and rarely quartz may be recognized. Of the dark minerals, glistening flakes of black biotite are the most noticeable, and the other important constituent has the dull greenish-black color and lath shape of hornblende. They all are about equal in size, as a rule not exceeding one-eighth of an inch.

Macroscopic variations in the rocks from different parts of the area seem limited chiefly to differences in the amount of dark minerals present and to slight tendencies toward porphyritic structure. But in the porphyritic rock the groundmass is coarsely crystalline, and in this respect differs macroscopically from the diorite porphyry discussed on another page. At the contact with sediments more striking variations were found. In two places where the sediments were limestones the periphery of the diorite showed a tendency toward pegmatitic rock. In one specimen in particular (P. U. 418.1) the selvage of the diorite was an intergrowth of quartz and pinkish feldspar.

Weathering has not penetrated deeply into the diorite mass. Long-exposed outcrops assume on the surface a rusty color; the biotite becomes bronzed through loss of iron, the hornblende turns greenish, and the feldspars grow dull or are stained brown by iron. Along fracture planes in mines, however, alteration has been much more extensive. There the rock takes on a gray appearance, the individual minerals become less distinct, and the mass is impregnated with pyrite. In extreme stages the rock becomes a soft dull-gray mass in which outlines of the minerals are only faintly visible, the biotite is bleached to white flakes, and the mass is stained brown by iron.

Microscopic features.—Under the microscope (see Pl. XII, *B*) the rock is seen to have granitoid texture and the minerals therefore are not well formed. Few crystal forms are preserved wholly intact, though in many places portions of crystal outlines are present. The essential minerals range in size from one-eighth of an inch to microscopic particles but are not so generally altered as the minerals of the andesites.

Of the chief minerals, plagioclase is much more abundant than hornblende or biotite, which are usually present in equal amounts. Orthoclase is generally at least as abundant as hornblende or biotite, and in some specimens equals plagioclase. Quartz is generally less in amount than any of the above-named minerals, but in one specimen (P. U. 509) it ranks between orthoclase and plagioclase. The usual accessory minerals are present, including apatite, magnetite, pyrite, and titanite.

The optical characteristics of the chief minerals are practically the same as those of the andesite phenocrysts described above. The hornblende, however, in at least one specimen shows pink and green pleochroic colors. The lime-soda feldspars range between albite and oligoclase, as shown by extinctions of albite and Carlsbad twins. They occur locally in microperthitic intergrowths with orthoclase, a characteristic not found in other rocks of this region, and accompanying the microperthite in one such occurrence considerable micropegmatite was noted.

Alteration in the diorites has been slight, being most prevalent in ferromagnesian minerals. Biotite is most frequently attacked and goes over to chlorite. Kaolin was noted from feldspar and some serpentine from hornblende. Augite where present may exhibit on its edges a secondary mineral having the microscopic properties of hornblende and probably belonging to uralite.

The dark varieties of diorite are seen to gain their color from large amounts of ferromagnesian minerals (P. U. 502, 413, 510, 516) and the lighter varieties show a coarser grain and less hornblende and biotite (P. U. 535, 536). The porphyritic tendency in certain localities is emphasized by different minerals. At Fall Camp hornblende is the phenocryst and at the head of Thaynes Canyon biotite alone or biotite and feldspar together are prominent crystals. The groundmass in these cases, however, is holocrystalline and represents a fine-grained diorite. The contact varieties of diorite show orthoclase, epidote, and hornblende as the prevailing minerals, but no specimen of the pegmatite mentioned above was studied under the lens.

Microscopic examination of the altered diorites reveals more or less complete alteration of all the constituent minerals but quartz. The feldspars are represented by muscovite and calcite mixtures penetrating the crystals, sometimes nearly replacing them. Orthoclase and plagioclase therefore are difficult to distinguish. Biotite has become bleached or changed to chlorite, and the resulting solutions combining with those from the feldspars appear to have formed epidote. Pyrite is rather plentiful and some limonite was observed. Excellent exposures of decomposed diorites were noted in the J. I. C. mine.

Chemical composition.—The analysis of a typical diorite of this district is given in column 1 on page 79, and of a quartzose facies in column 2, and an analysis of a diorite from California is put in column 3 for comparison.

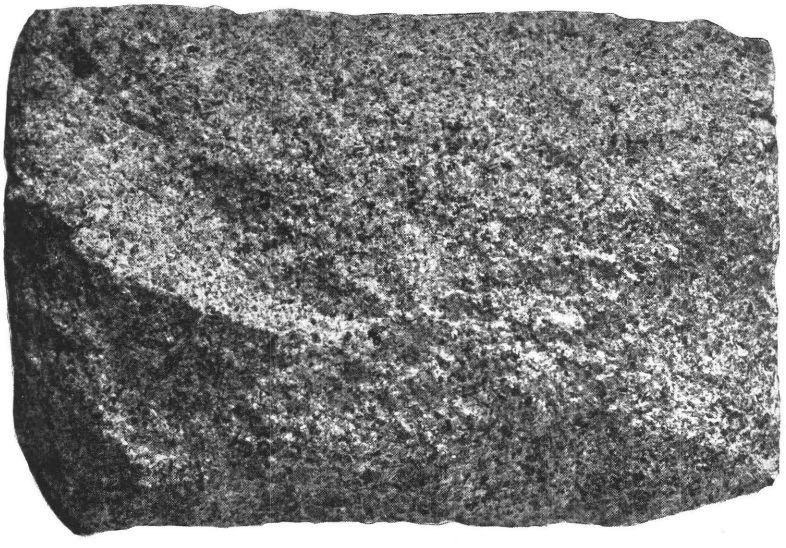
PLATE XII.

PLATE XII.

QUARTZ DIORITE.

A. Hand specimen showing a light-gray rock of medium fine texture with augite or hornblende and biotite (dark areas) intergrown with plagioclase feldspar and some quartz (light areas). Natural size. From Clayton Peak stock, upper Bonanza Flat.

B. Photomicrograph showing granular structure, medium grain, with tendency toward phenocrystic plagioclase. The plagioclase (*p*) is more abundant than quartz (*q*), which in turn is more abundant than orthoclase (*o*), which is about equal in amount to hornblende (*h*) but more abundant than biotite (*b*). Some apatite, titanite, and pyrite are present. Slight alteration by kaolinization and chloritization has taken place. × 35.



A. HAND SPECIMEN.

B. PHOTOMICROGRAPH.

QUARTZ DIORITE.

Analyses of quartz diorites.

	1	2	3		1	2	3
SiO_2	59.35	63.46	57.26	SO_3	None.	None.	.....
Al_2O_3	16.36	15.93	16.51	Cl	.05	.05	.....
Fe_2O_3	2.90	2.61	3.27	F	(?)	Trace?	.....
FeO	3.36	2.31	5.19	FeS_2	.02	[a](0.01 S)	.....
MgO	3.08	2.27	3.41	Cr_2O_3	None.	None.	None.
CaO	5.03	4.33	6.69	MnO	.07	.09	.18
Na_2O	3.73	3.66	2.65	BaO	.16	.15	.10
K_2O	3.85	3.49	2.93	SrO	.05	[b]	.06
H_2O-	.28	.27	.20	Li_2O	Faint trace.	Faint trace.	Trace.
H_2O+	.64	.74	.95	ZnO	.01	.....	.....
TiO_2	.87	.62	.53	CuO	.01	.....	.....
ZrO_2	.03	.03	.....				
CO_2	Trace?	Trace.	None.		100.29	100.17	100.23
P_2O_5	.44	.16	.30				

[a] Trace from pyrrhotite.

[b] Included in CaO above.

1. Quartz diorite, three-fourths of a mile northeast of Clayton Peak. W. F. Hillebrand, analyst.
2. Quartz diorite, east side of Brighton Gap. W. F. Hillebrand, analyst.
3. Quartz diorite, east of Milton, Sierra County, Cal. Turner, H. W., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 724.

No. 2 differs from No. 1 chiefly in the amount of silica present derived from quartz. The former probably represents about one-fourth of the diorites examined, the remaining three-fourths resembling No. 1 more closely. The percentages of K_2O are in accord with the occurrence of orthoclase in these rocks but seem not sufficient to rank them among monzonites. Considered with regard to both the chemical and the mineralogic composition, the rock appears hardly to be a true diorite but rather a diorite with a quartzose phase and a monzonitic tendency or, according to the recent classification, No. 1 is shoshonose and No. 2 hartzose.

Facies.—Certain allied rocks in minor areas, because of absence of conclusive field evidence as to their relative ages and geologic relations, are discussed here as facies of the quartz diorite mass. They are confined in general to the vicinity of Brighton Gap, extending to Shadow Lake on the east and occupying at the west the spur south of Brighton road. They differ from the quartz diorites as viewed by the unaided eye in being commonly coarser and having a larger proportion of light minerals and a dash of pink in their prevailing gray color. These rocks are somewhat unevenly granular, hence in texture they stand intermediate between the diorites and diorite porphyries of this district. Their composition is very similar to that of the diorites, though the pink tinge allows the supposition of prevalent potassic feldspars.

Under the lens the mineral proportion shows a larger amount of quartz than is common in the diorites but similar proportions of the other components except orthoclase, which is somewhat higher. The orthoclase in some slides comprises considerable micropegmatite and microperthite, and the plagioclase is generally oligoclase or less commonly albite.

These rocks, therefore, may be considered a somewhat stronger expression of the quartzose monzonitic tendency of the granular rocks in this area, but not such as would necessarily, in the absence of field evidence, be attributed to different eruptions.

QUARTZ DIORITE PORPHYRY.

Definition and general description.—Diorite porphyry has come to mean a rock of the diorite variety some of whose constituent minerals occur as distinct phenocrysts. When this rock contains appreciable amounts of quartz it is designated quartz diorite porphyry. In the Park City area some quartz is almost always present, but augite is sparse and the rocks are commonly confined to dike occurrences.

As a rule quartz diorite porphyries are spotted rocks. The spots most noticeable are whitish, but scrutiny may disclose some dark spots. The spots are large crystals, called phenocrysts, which are generally the only recognizable minerals and consist prevailingly of whitish feldspars, the dark, small hornblende, biotite, and possibly augite crystals being less conspicuous. In composition such rocks stand well within the limits stated under "Diorite," except that the presence of much quartz may run the silica content up to 67 per cent.

Macroscopic features.—The usual appearance of the diorite porphyries of the Park City district in the outcrop is that of light-gray, faintly spotted rocks (Pl. XIII, *A*). On new frac-

ture the phenocrysts stand out more distinctly in a dark groundmass. Close examination shows that the color of the rock lies in the groundmass, which runs through shades of drab or deep bluish or greenish gray. It is also seen that the phenocrysts are not confined to the light feldspars but include indistinct crystals of the dark ferromagnesian minerals—hornblende, biotite, and, rarely, augite. In some fresh specimens the shining facets of the feldspars are etched with the multiple twinning of the plagioclases, and in others, especially in altered samples, may be discerned fragments of rough greasy quartz. The groundmass even under a hand glass appears to be no more than a fine crystalline mass of ill-formed minerals. Among these may be recognized with difficulty particles of biotite, feldspar, and pyrite.

The phenocrysts vary widely in size. Few reach over half an inch in their greatest length. Relatively the plagioclases develop the largest phenocrysts; next rank the hornblendes, which rarely attain a length greater than a quarter of an inch; finally the dark-brown micas, which here and there outmeasure the hornblendes but very generally are smaller in diameter though equivalent in area. Quartz, where it occurs as phenocrysts, very rarely measures more than an eighth of an inch in diameter, and augite is scarcely ever noticeable. In the shape of the phenocrysts there is also a wide range. Normally the feldspars approach oblongs and squares; the hornblendes occur in prismatic laths or diamond-shaped cross sections, which distinguish them from augites; and biotite in hexagonal flakes. Quartz generally displays no crystal form but occurs as more or less rounded or corroded fragments.

The above description is typical of nearly all the diorite porphyries of this district, but there are slight variations in appearance and composition which should perhaps be noted. In a few places the rocks assume an unusual pinkish (P. U. 403, 416) or whitish (P. U. 507) color or a brownish and extraordinarily dark appearance (P. U. 405, 411). The lighter colors are apparently due to orthoclase; the darker shades may be laid to the preponderance of some ferromagnesian mineral. For example, one specimen (P. U. 447) from a narrow dike has a dark-drab color and is composed largely of biotite. The phase with striking quartz phenocrysts need not be described, and that with augite may be dismissed with the statement that only about one-tenth of the specimens show this mineral.

A few rocks showed variations in texture which, unless they were otherwise obviously related to typical diorite porphyry, would have been sufficient to class them in another group. These occur along the periphery of the larger masses or in narrow dikes where conditions attending the congelation of the magma were unusual. In these localities the texture tends to imitate that of true diorite. Thus certain selvage zones are exactly comparable to diorite in appearance, and other selvage phases and in places whole dikes assume a subporphyritic structure.

Weathering and other agencies may change the appearance of the diorite porphyries and disguise their true relationships. The early effects are noticeable, first, from changes in the phenocrysts. Thus hornblende or biotite may be replaced by flakes of secondary chlorite (P. U. 526) or by green patches of epidote (P. U. 527). Continued alteration dulls the faces of the feldspars and renders the crystals dead white or discolored by solutions of decomposition. Finally, the rock may become a white-streaked chalky mass (P. U. 441, 443), deeply pitted, and exceedingly porous. In this stage the porphyritic structure is almost imperceptible or at most is shown by indistinct remnants of dull feldspar, fresh grains of quartz, bleached scales of biotite or secondary mica, and mere outlines of the other phenocrysts. Types of extreme alteration are well displayed on the ridge between McCune Hollow and McHenry Gulch.

The hand specimens also exhibit some curious changes due to mineralization of the original rock. For instance, many of them, especially those appearing somewhat decomposed, are pregnant with minute cubes of iron pyrites. One specimen (P. U. 1074) from the 1,700-foot level of the Ontario mine contained sphalerite and galena in addition to pyrite. One or two specimens were observed in which nearly the entire groundmass had apparently become silicified. In these specimens the rock had become abnormally light in color and at the same time dense and siliceous in appearance, though perhaps somewhat porous.

PLATE XIII.

PLATE XIII.

QUARTZ DIORITE PORPHYRY.

A. Hand specimen of rather coarsely porphyritic rock, showing fresh crystals of hornblende, plagioclase, some biotite, and pyrite in a gray crystalline groundmass. Natural size.

B. Photomicrograph showing phenocrysts of plagioclase (*p*), altered hornblende (*h*), and biotite (*b*) in that order of abundance, in about an equal amount of holocrystalline granitic groundmass composed of about equal amounts of feldspar, chiefly orthoclase, and quartz, with grains of ferromagnesian minerals. Some pyrite and chlorite are present. × 35.

A. HAND SPECIMEN.

B. PHOTOMICROGRAPH.

QUARTZ DIORITE PORPHYRY.

Microscopic features.—The microscope shows the rock to be as a rule medium grained and porphyritic (Pl. XIII, *B*). The phenocrysts appear to form in general about half of the rock, though there are a few exceptions where they constitute either a very insignificant or a largely preponderant part. They range from crystals half an inch in greatest dimension down to microlitic forms not much larger than the crystal grains of the groundmass. This diversity in size is greatest among the feldspars, which form the largest phenocrysts, less among the hornblendes, and least among the micas and other mineral components. The phenocrysts also vary considerably in shape and perfect crystal outlines are seldom seen. Part of the crystal form is usually apparent, the remainder having been broken or dissolved away. The quartz phenocrysts, however, are always rounded and corroded. Here and there all the phenocrysts are greatly shattered and possibly contorted. The groundmass of course contains few if any crystal forms, being granitic in structure and generally of very fine to medium texture. Very rarely a slide reveals a coarsely crystalline groundmass; more commonly the sections display a microlitic mass, with locally some glassy base and usually distinct flow structure. The microscope brings to light much alteration not apparent in the hand specimens; in fact, a perfectly fresh rock was difficult to find. The alteration as usual first attacks the ferromagnesian components, leaving intact the feldspars as a rule and the quartz where present.

As already suggested, the microscope confirms the presence of the usual diorite minerals—plagioclase, hornblende, and biotite prevailing; orthoclase, quartz, and augite occurring in small amounts; and the usual accessories, including zircon, magnetite, apatite, and titanite present. Of the chief minerals, those which constitute the phenocrysts most usually occur as to amount in the following order: Plagioclase (albite-oligoclase), hornblende, biotite, quartz, with small amounts of magnetite. But in parts of the rock this order changes so that plagioclase and hornblende occur in equal quantities or hornblende in excess of plagioclase. Quartz may exceed biotite, and in one specimen both quartz and biotite exceed plagioclase. Augite where present commonly replaces hornblende. Fragments of orthoclase may also occur among the minor phenocrysts.

In the groundmass the rank of the component minerals is not clear, because of the minute, indistinct, or decomposed character of the material. To judge from the fresher specimens, plagioclase is by far the most predominant mineral, quartz occurs in small amounts, and orthoclase may or may not be present. Where orthoclase is present, it is commonly subordinate to plagioclase, though occasionally equaling and rarely (as in Wasatch Gulch) even exceeding it. In one or two specimens from the low divide at the head of Empire Canyon the microscope discloses a groundmass composed largely of micropegmatite with plagioclase inferior to orthoclase. In addition to these light-colored components the groundmass generally contains fragments of the darker phenocrystic minerals and of the accessories. Among the latter apatite, titanite, zircon, and magnetite are the most prominent. Here and there between the groundmass crystals were noted small areas of dingy isotropic glass, which in at least one slide was the predominating component of the groundmass.

The minerals found in the diorite porphyries being practically the same as those in the diorites, the reader is referred for notes on their optical appearance to the microscopic description of those rocks (p. 76).

Alteration in the diorite porphyry, though not generally so profound as in the andesite, has taken place everywhere to a moderate degree. (See Pl. XV, *A*.) As a rule the ferromagnesian minerals are affected. In the incipient stages of alteration hornblende and biotite are merely bleached, but further disintegration develops usually chlorite (serpentine) and calcite and commonly limonite and epidote, and the final stages are marked by the presence of secondary quartz. The feldspars when decomposed are generally changed into kaolin and sericite or paragonite. In two slides (P. U. 441, 443) the plagioclases had completely disappeared save their outlines, which were filled with sericite flakes. Through alteration magnetite may take on a brown halo of limonite and the groundmass become a more or less kaolinized mat containing whitish patches of calcite and green films of chlorite. Finally, the amorphous base may by devitrification become a recrystallized glass.

The whitish chalky stages of alteration of the whole rock reveal very little under the microscope. The spur at the head of McCune Hollow offers typical specimens of such rock. In these (P. U. 441, 443) the groundmass appears to be sericitized, devitrified, and perhaps silicified, and the phenocrysts are marked by little more than outlines, which inclose scintillating masses of sericite (from feldspar?), fibrous strings of mica (biotite?), and limonitic areas (from magnetite?), in places mixed with sericite (from a ferromagnesian mineral?).

The process of mineralization partly evident in the hand specimen is much more conspicuous under the microscope. Fine hairlike fractures are disclosed which carry veins of secondary quartz, and every part of the rock appears to be impregnated with pyrite. This sort of pyritization has probably occurred in 75 per cent of the rocks, but silicification is more rare. A specimen from the Crescent dump (P. U. 622), whose silicification was evident in the hand specimen, is a striking example of this sort of alteration. The phenocrysts are masses of sericite, and the larger part of the groundmass is a fine mosaic of quartz, with a few sericite patches, the whole being cut by iron-stained quartz veins. One slide (P. U. 1042) of porphyry from a contact with limestone exhibited waxy anisotropic patches of garnet, together with chalcopyrite, pyrite, and perhaps other metallic minerals.

Microscopic study of the pinkish and whitish rocks described above (P. U. 403, 416, 501, 507) shows in the groundmass an unusual amount of orthoclase which probably accounts for their light color. On examining the dark rocks it is seen that one (P. U. 405) abounds in augite, another (P. U. 411) is stained with a brownish limonitic alteration product of biotite and perhaps augite, and a third (P. U. 447) bristles with dark biotite flakes predominating over the phenocrysts and invading the groundmass.

The structural facies of those diorite porphyries which to the naked eye suggest the normal granular diorites are confirmed under the microscope. Porphyry dikes, for instance, on the 1,500-foot level of the Ontario mine near shaft No. 2 (P. U. 1042), furnish selvage zones exactly comparable in structure and composition to normal diorite. In a thin section from the Parleys Park shaft (P. U. 501) a similar contact variation is shown, but the rock is much finer and is subporphyritic. This latter phase may pervade an entire intrusion, as in the dike on Jupiter Hill (P. U. 507) and on the 440-foot level of the J. I. C. (P. U. 1020). But the periphery of the diorite porphyry masses does not always show either granular or subporphyritic facies, for a sample from the frozen contact of a dike in the Wabash mine, 600-foot level (P. U. 1012), is as perfectly porphyritic as any specimen from the interior of the dike. In addition to being perfectly porphyritic at the contact another specimen (P. U. 656.2) exhibited brecciation of the groundmass, resembling a flow breccia.

Chemical composition.—Two analyses of the diorite porphyries have been made and are given below, one from the ordinary variety typical of this district and another from a more quartzose phase. With these is placed for comparison an analysis of a similar diorite porphyry from Colorado.

Analyses of quartz diorite porphyries.

	1	2	3		1	2	3
SiO_2	59.68	61.64	60.44	ZrO_2	.01	.01	.....
Al_2O_3	15.61	14.66	16.67	P_2O_5	.29	.24	.29
Fe_2O_3	2.49	1.95	2.31	CO_2	2.29	2.15	.48
FeO	2.38	1.68	3.09	FeS_2	.02	.32	.....
MgO	2.52	2.55	2.18	MnO	.08	.06	.13
CaO	4.63	4.65	4.22	BaO	.15	.18	.12
Na_2O	3.96	2.71	5.18	SrO	.07	.06	.11
K_2O	2.92	3.07	2.71				
H_2O	2.51	3.60	1.43		100.23	100.00	99.96
TiO_2	.62	.48	.60				

1. Quartz diorite porphyry from dike northwest of Daly West shaft. W. F. Hillebrand, analyst.
2. Quartz diorite porphyry from Valeo mine, Cottonwood Canyon. W. F. Hillebrand, analyst.
3. Diorite porphyry from Deadwood Gulch, La Plata Mountains, Colo. W. F. Hillebrand, analyst. Cross, Whitman, La Plata folio (No. 60), Geol. Atlas U. S., U. S. Geol. Survey, 1899.

These analyses rank well toward the acidic end of the diorite group, being high in silica. Probably one-third of the specimens taken contain enough quartz to be ranked with No. 2 of the table. Alumina and ferrous iron occur in somewhat smaller amounts than ordinarily, and soda,

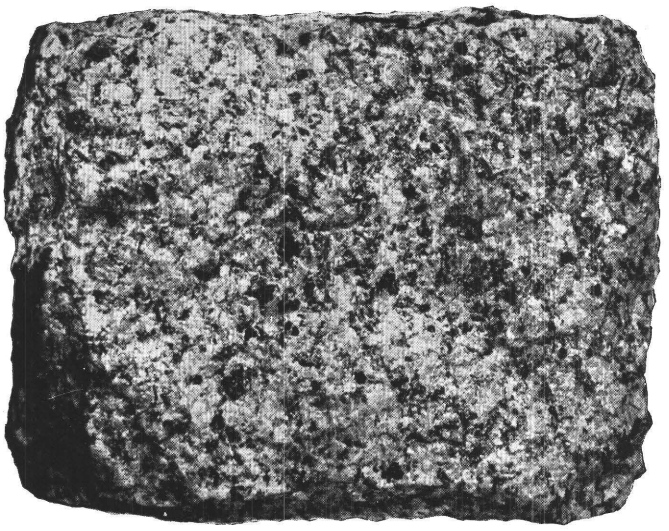
PLATE XIV.

PLATE XIV.

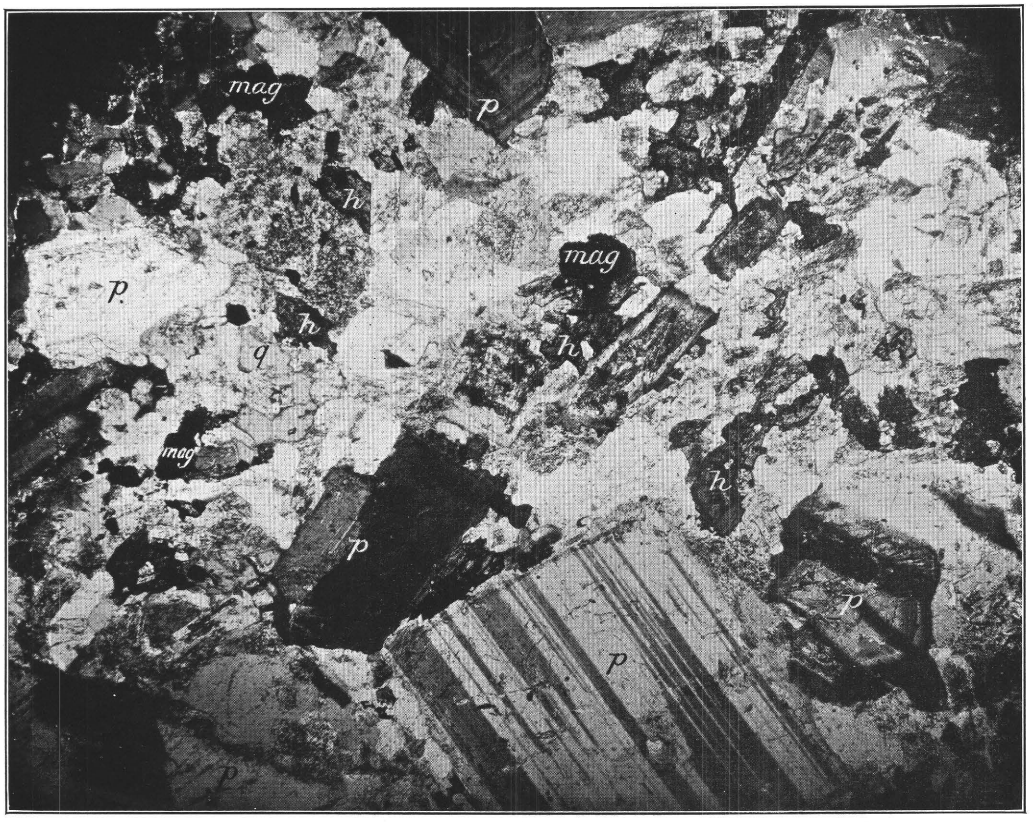
COARSE FACIES OF QUARTZ DIORITE PORPHYRY.

A. Hand specimen showing coarsely crystalline rock made up of feldspar, biotite, hornblende, and augite. Natural size.

B. Photomicrograph showing well-formed phenocrysts of plagioclase (*p*) and fragments of hornblende (*h*) (biotite not showing), named in the order of abundance, grading into a coarsely crystalline groundmass composed of feldspar, largely orthoclase, and some quartz (*q*) and magnetite grains. × 40.



A. HAND SPECIMEN.



B. PHOTOMICROGRAPH.

COARSE FACIES OF QUARTZ DIORITE PORPHYRY.

though averaging well in No. 1, is slightly low in No. 2. Potash, however, is somewhat higher than normal and this accounts for the prevalence of some orthoclase in the diorite porphyries. This fact brings the rocks under discussion nearer the composition of true diorites than the rocks described under that heading, though both lie on the border line between diorites and monzonites. The presence of considerable carbonate no doubt represents the decomposition uniformly pervading this rock.

In view of the mineral composition and structure as revealed both in the hand specimen and under the microscope and the chemical constitution shown by the analyses, this rock may be designated diorite porphyry with a distinct quartz phase and a slight monzonite tendency. According to the precise system given in the "Quantitative classification of igneous rocks" this rock belongs under hartzose. The relative amounts of the minerals found in this rock probably approximate those of the table given on page 92, although of course the albite and anorthite given in this table are combined in the rocks as plagioclase.

GRANITIC DIKES.

Definition and general description.—The term granite is of broad application, but in its restricted signification means a granular igneous rock consisting of quartz, orthoclase, oligoclase, biotite, and muscovite in proportions about in the order named. Small amounts of hornblende or augite may be present, but they are not essential. Such rocks have prevailingly a pinkish-gray color, though untinted and bluish-gray granites are also common, the colors depending on the feldspars. Owing to the predominance of quartz and orthoclase the chemical analyses of granites disclose larger percentages of silica (66 to 74) and potash (2 to 8) than are contained in any rocks from the Park City area yet described. Alumina rarely reaches 18 per cent, and from the paucity of plagioclasic minerals, soda and lime seldom reach 4 per cent. No analyses of the granitic rocks from the dikes of this district were made, but it will be seen from the descriptions below that the term "granite" can not be applied to them in its strict significance, hence the adjective termination is used to show that the word indicates merely the kinship of these rocks and is not intended to name them specifically. Their common mode of occurrence is in dikes cutting the quartz diorites and they may prove to be arms of larger bodies lying on the west.

Macroscopic features.—In fresh specimens (see Pl. XIV, *A*) the most striking characteristic of the granitic rocks is their pink color, and aside from this they are not in appearance widely separated from the diorites, except that the dark components of the latter are less conspicuous and probably less abundant. They are generally fine grained and little, if at all, inclined to the porphyritic habit. Their granular surfaces sparkle with crystal facets of feldspar and glassy fractures of quartz; among which is a dash of greenish minerals showing the prism sides of hornblende and paper-like scales of biotite. Of such rocks are three-fourths of the dikes, but one on Pioneer Ridge is surprisingly different in appearance. Its color is changed by the elements to a greenish tinge, and though the weakly colored flakes of mica still retain some biotite bronze, most of the mica resembles chlorite and probably endows the rock with its greenish color.

Microscopic features.—On study with the microscope the grain is found to be hypidiomorphic to allotriomorphic, few minerals preserving even fragments of crystal outline but presenting an irregular mosaic of feldspar, quartz, and biotite or hornblende. Of these constituents quartz is always very prominent, alternating first or second in rank with orthoclase or plagioclase. Orthoclase is on the whole more abundant than plagioclase, and in half the sections, including the one from Pioneer Ridge, much more so. The darker minerals, which prove to be biotite or hornblende more or less changed to chlorite and epidote, always rank a poor fourth. The accessories, titanite and apatite, complete the mineral composition of these rocks, except for small amounts of the common secondary products kaolin, pyrite, calcite, and limonitic stains.

Conclusion.—Thus it is evident from the abundance of quartz, the prevalence of orthoclase, and the inferiority of plagioclasic and ferromagnesian components that these dikes do not fall

in well with any of the rocks already described. They are perhaps most closely related to the Brighton Gap mass, which on negative evidence and for convenience is given as a facies of quartz diorite. Yet from this facies they are widely separated in relative amounts of plagioclase, orthoclase, and quartz, this being roughly the relative order for these minerals in the Brighton Gap mass. It seems, therefore, that these dikes, reaching perhaps beyond the monzonite mark, represent the extreme granitic end of the rock series found in this district.

PERIDOTITE (PICRITE) DIKES.

Definition and general description.—Rocks of a granitoid structure and consisting of olivine and pyroxene with little or no feldspar are commonly called peridotites. Of these many varieties have been named according to the kind of pyroxene present or its substituted mineral. Olivine is the critical component; without it a rock is not a peridotite. In addition to pyroxene small amounts of other ferromagnesian minerals such as hornblende and biotite may occur. Magnetite also is commonly present.

The name picrite has been used to designate those rocks belonging to the peridotite group which have abundant and large phenocrysts of olivine with less augite and little or no biotite and hornblende in a glassy groundmass. This hyaline base may be more or less devitrified. In general appearance picrite is a dense fine-grained rock of very dark color, set with the glistening facets and elevated forms of dark minerals. It is, therefore, of porphyritic texture, the recognizable minerals being limited to olivine and biotite.

The peridotites reach a lower percentage of silica than any rocks already described, the limits being 30 and 47 per cent. Alumina forming 2 to 8 and rarely 9 per cent of the rock is also low, but the iron oxides (7 to 15 per cent), lime (nearly equal), and magnesia (15 to 30 per cent) average high. Soda and potash, prominent in the rocks so far described, here make up only 2 or 3 per cent.

Macroscopic features.—The only occurrences of peridotites in the Park City district are in the Alliance tunnel and the Silver King mine. Fresh specimens from these dikes represent a dark rock the greater part of which is dense and microcrystalline. Attractively set in this groundmass are little shiny plates of a very dark mica surrounded by less conspicuous but larger, greenish, somewhat decomposed crystals of olivine, which form considerably the larger part of the phenocrysts. Few of these reach an eighth of an inch in length. The mica, which is no doubt brown biotite, figures less prominently among the phenocrysts, measuring here and there an eighth of an inch, but grading down to small particles. In the groundmass very little can be discerned with certainty aside from biotite scales, but in places fragments of augite or hornblende and black grains of iron oxide are seen.

The macroscopic differences between the two dikes are very slight, and perhaps the most notable is the seeming prevalence of biotite in the rock from the Alliance tunnel. The effects of weathering scarcely catch the eye except the greenish color of the olivine phenocrysts, which are probably partly altered to serpentine.

Microscopic features.—With the aid of the microscope the rock is seen to be a fine-grained porphyry in which the groundmass somewhat exceeds the phenocrysts (Pl. XV, *B*). The phenocrysts are on the whole well formed, olivine being conspicuous by its broad solid laths, with rough cross fracture and normally with pointed ends, and biotite showing as slender fibrous laths or truncated papery flakes. In the groundmass the minerals are more nearly idiomorphic than in the diorites, the prevalent constituent approaching lath shapes and the less prominent being ill formed. These, as well as the phenocrysts, have a fresh, unaltered appearance, except the olivine and possibly the biotite.

The microscope discloses the fact that the dark color of the rock is in great measure due to the preponderance in the groundmass of augite, which occurs regularly as laths. The interstitial spaces are largely filled with magnetite grains and leaves and palings of biotite, both contributing to the general dark color. The trifling interstitial space remaining is filled with a clear-white glass.

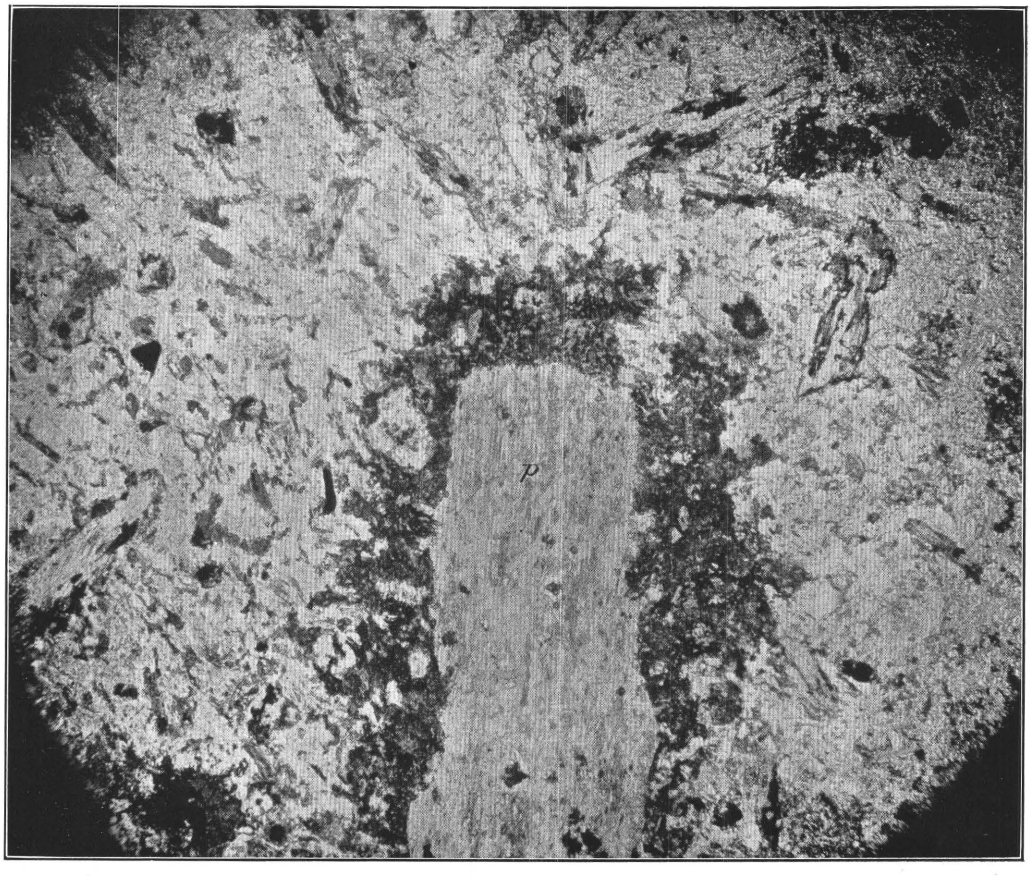
PLATE XV.

PLATE XV.

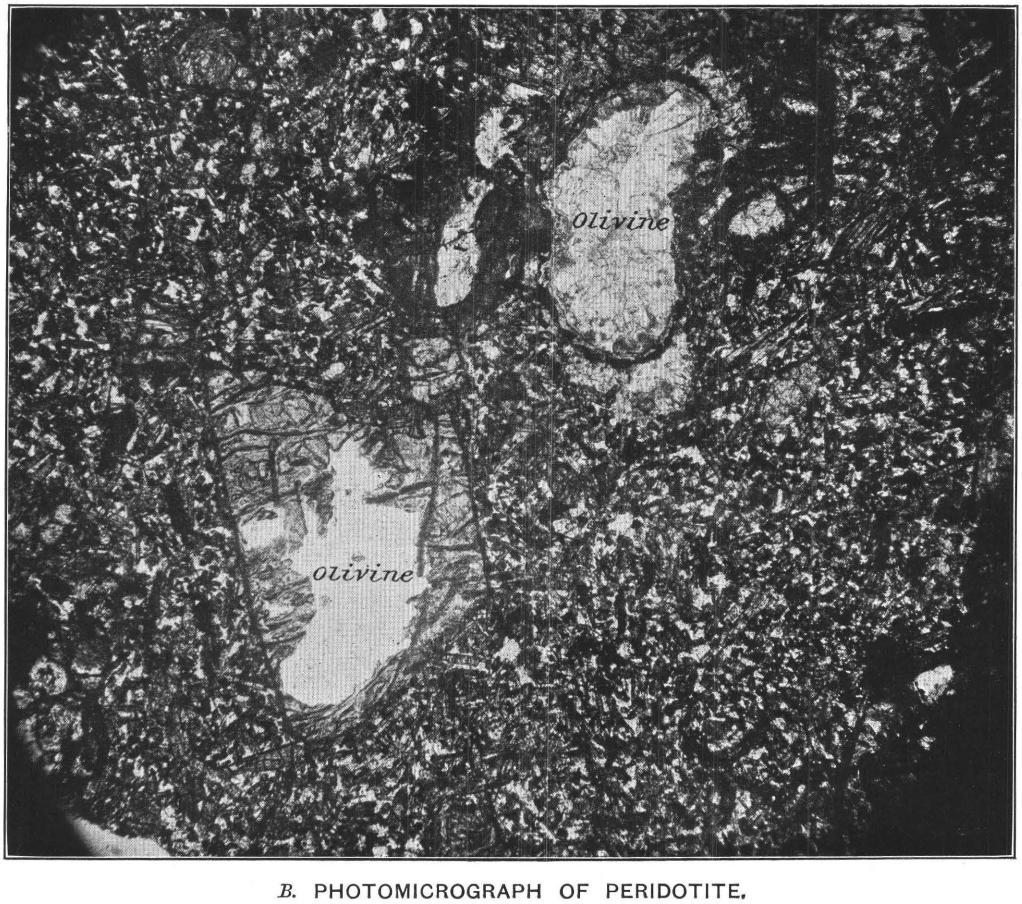
Altered diorite porphyry and peridotite.

A. Photomicrograph of diorite porphyry, showing large altered feldspar phenocryst (*p*), some hornblende, and pyrite in granular crystalline groundmass made up chiefly of feldspar, mainly plagioclase, with some quartz and fragments of phenocrysts. The feldspars and the ferromagnesian minerals are much altered, and the alteration products, chlorite, calcite, epidote, leucoxene, and secondary mica, are abundant. Considerable pyrite and ilmenite are present. × 35.

B. Photomicrograph of peridotite, showing phenocrysts of olivine in fine-grained groundmass composed of laths of augite, abundant grains of magnetite, and flakes of biotite in a glassy base. The replacement of olivine by serpentine is seen in its initial stages along cracks in the large crystals. × 35.



A. PHOTOMICROGRAPH OF ALTERED DIORITE PORPHYRY.



B. PHOTOMICROGRAPH OF PERIDOTITE.

The uncommon mineral of this rock, olivine, is characterized by its stout, pointed boat shape, by its very strong double refraction, giving an order of colors approximating those of muscovite, and by the absence of extinction angles. In these specimens also it is unique in exhibiting along the cleavage cracks various stages of serpentinization. The associated augite with which it may be confused is of a grayish cast, more distinctly cleaved, and broadly extinguished. Prism sections of the augite are slender laths and cross sections are nearly squares with truncated corners and two cleavage systems crossing almost at right angles. Biotite is distinct from these two minerals in its strong pleochroism, low relief, masked interference colors, and rippling hair-lined cleavage. In these rocks, however, the centers of the biotites are light colored and consequently produce high colors with crossed nicols. The other components are less important, but magnetite may be recognized as black grains by all lights except incident light, in which it displays a metallic luster and minutely grained surface. The glassy base is grayish to colorless in polarized light but, being amorphous, is constantly dark under crossed nicols.

The specimens of these rocks, having been obtained in mines several hundred feet underground, show even under the microscope very little tendency to alteration. Indeed, decomposition is apparently limited to olivine, though the light centers of the biotite may possibly be due to bleaching. Serpentine, the usual alteration product, fringes the edges and particularly the interior cracks of the fragments of olivine with projecting fibers but has left untouched the inner portions of the mineral. Serpentinization has progressed further in the Alliance tunnel rock than in the sample from the Silver King; still, in the latter, serpentine may bear black dust of magnetite as a companion product of alteration.

No chemical analysis of this rock was made.

PETROLOGIC RELATIONS.

The volcanic rocks of the Park City district are closely related by texture, mineral character, and chemical composition. There is not so much resemblance in texture as in other respects, for all the rocks do not present the same arrangement of minerals. The diorites and the other granular rocks lying to the west, in Little Cottonwood Canyon, exhibit a granitoid mineral arrangement, but the intrusive and flow rocks in the middle and eastern parts of the district are distinctly porphyritic. Thus the andesites are always phenocrystic and the diorite porphyries generally so, but in places the magma of the latter approaches the diorites in texture. The three porphyritic rocks—diorite porphyry, andesite, and peridotite—are texturally indistinguishable in hand specimens, and under the microscope the andesite and peridotite are often found to be very similar to each other but distinct from the diorite porphyry in having a glassy base.

In mineralogic composition these rocks are more obviously related than in texture. Thus in the three main rocks—andesite, diorite, and diorite porphyry—plagioclase is nearly always the dominating constituent and hornblende, biotite, and quartz are prevalent usually in the order named, though any one may predominate in a particular rock or group. Orthoclase is a common constituent of the diorites and the porphyries, in which it probably ranks above or with hornblende, but in the andesites it is rarely seen. Augite is the vagrant component and appears sporadically in all members of the group. But in the two specimens in which it preponderates over the other minerals, feldspar, hornblende, and quartz disappear and the rock changes its habit and takes on olivine.

In chemical constitution the rocks analyzed do not differ to any great extent. The greatest difference among the chief oxides is about 10 per cent in silica, and leaving out andesite it is only about 5 per cent, even with the "granite" of Little Cottonwood Canyon included. The quartzose phase of the diorites is thus clearly evident from the analyses. The other principal oxides range generally within 1 per cent, but in alumina the variation reaches 2 per cent. In andesite, however, the average range in alumina, ferric oxide, and lime is exceeded by 1 per cent; diorite shows a like increase in range of ferrous oxide; and the "granite" of Little Cottonwood Canyon

is below the general average range in magnesia. Among the less important constituents, pyrite is 16 times as plentiful in the quartz diorite porphyry as in any one of the other rocks. Carbon dioxide, too, is prominent only in the porphyries.

The rocks show further marked relations when the ratios of the several oxides to one another are compared. Indeed, the quantitative system of rock classification has been elected partly on such ratios and partly on a theoretical mineral composition which is calculated from rock analyses.[1] The class and order in this system to which a given rock belongs depend upon the theoretical composition and the rang and subrang are fixed by the actual ratios. By means of this system the theoretical amounts of quartz and feldspars in the analyzed rocks from the Park City region were calculated and are given in the table below.

Mineral composition of rocks analyzed.

Rock.	Locality.	Quartz.	Orthoclase.	Albite.	Anorthite.	Total.
Andesite (P. U. 877)	Ontario drain tunnel	9.24	16.68	25.15	25.85	76.92
Diorite (P. U. 541)	¾ mile northeast of Clayton Peak	8.88	22.80	31.44	16.40	79.52
Quartz diorite (P. U. 509)	East side of Brighton Gap	16.86	20.57	30.92	16.68	85.03
Diorite porphyry (P. U. 533)	West of Daly West mine	13.02	17.24	33.54	16.12	79.92
Quartz diorite porphyry (P. U. 530)	Valeo mine, Cottonwood Canyon	20.88	18.35	23.06	18.63	80.92
Quartz monzonite (Cd. U. 17)	Little Cottonwood Canyon	19.68	19.46	33.01	15.57	87.72

According to these figures, which probably approximate the actual proportions of the minerals, quartz and the three feldspars compose over 77 per cent of the rocks analyzed and their ratios to those of similarly reckoned ferromagnesian minerals range between 4.06 and 7.8. All these rocks therefore fall in Class II of the quantitative classification except quartz monzonite, which is placed in Class I, though almost on the border line. The ratios of the quartz to the sum of the three calculated feldspars is much narrower, ranging between 0.194 and 0.34. Thus four rocks belong under the fourth order and the other two in the fifth. To this point the rocks have been classed by comparisons between calculated theoretical minerals; further denomination depends on the ratios between the actual percentages of potash, soda, and lime present in the rocks. Thus the proportion of potash and soda to lime—ranging from 0.86 to 1.75—varies somewhat more than the ratio of quartz to feldspars, and four of the rocks fall into rang 3 and two into rang 2. The ratios of potash to soda, however, are very close—0.747 to 1.13—so that the rocks are classed under a single subrang.

Classification of the igneous rocks of the Park City district according to the quantitative system.

Name.	Class: $\frac{\text{Silico-aluminous minerals}}{\text{Ferromagnesian minerals}}$		Order: $\frac{\text{Quartz}}{\text{Feldspars}}$		Rang: $\frac{K_2O+Na_2O}{Ca}$		Subrang: $\frac{K_2O}{Na_2O}$
	I. Persalane, 7 or more.	II. Dosalane, 1⅔ to 7.	4. Quardofelic, 0.6 to 0.14+	5. Perfelic, 0.14+ or less.	2. Domalkalic, 1.6 to 7.	3. Alkalicalcic, 0.6 to 1.6.	3. Sodipotassic, 0.6 to 1.6.
Andesite		4.42		0.136		0.863	0.945
Quartz diorite		4.06		.127		1.50	1.03
Do		6.11	0.24		1.65		.9+
Quartz diorite porphyry		5.17	.194			1.50	.747
Do		5.25	.34			1.24	1.13
Quartz monzonite	7.8		.28		1.75		

GEOLOGIC RELATIONS.

Relations of igneous masses to one another.—The field data and petrographic and chemical studies fail to afford conclusive evidence upon the relative age and other geologic relations of the three principal igneous masses. The diorite has not been observed to cut or be cut by the diorite porphyry. At the head of Thaynes Canyon these two rocks occur in various but somewhat contradictory and vague relations. At the southwest head of Empire Canyon, in the vicinity of the Daly-Judge shaft, typical diorite porphyry occurs, and a tongue of characteristic diorite, clearly an extrusion from the main body, is exposed in close proximity, but so far as

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

observed not in actual contact. Similarly in Bonanza Flat, immediately southwest of the southeast head of Empire Canyon and just east of the J. I. C. shaft, diorite extends northeastward into close proximity to the porphyry mass, but their relation could not be determined, nor could they be separated for purposes of mapping. So far as petrographic and chemical data throw any light on the problem, they permit either the unity or the individuality of the masses. In brief, although obscure evidence and general features suggest that these two igneous rocks are geologically distinct, conclusive evidence on their geologic relation was not observed.

No conclusive field evidence as to the geologic relation of the diorite porphyry to the andesite was found. No case of the actual passage of porphyry as an intrusive upward and out into andesite as an extrusive, thus indicating their contemporaneity, was observed. The best evidence of this relation was found on the extreme northern edge of the district mapped, toward the western margin of the extrusive area. (See Pl. II, p. 44.) Fragments and a considerable oval area of porphyry are here included in the andesite and would thus appear to be earlier. Further, this porphyry proves to be petrographically the same as the perfectly characteristic facies which outcrops in the neighborhood of the Valeo mine. It follows that if the porphyry in the andesite of this area is earlier and if it is contemporaneous with the Valeo rock and the other porphyries of the district, then the porphyry as a whole is older than the andesite. Additional evidence, similar in every way to that observed in the Bingham district, is found in the fact that the andesite fills, wraps around, and blankets an old topography which to every appearance was developed on the porphyry and therefore after its intrusion. From these facts it follows that the andesite is not only of a distinct and later date than the diorite porphyry, but that sufficient time elapsed after the date of intrusion and before the date of extrusion to allow extensive erosion. Hence, the weight of evidence tends to indicate that the porphyry and andesite assumed their present state at different dates—the andesite being notably later.

Relations of igneous rocks to sediments.—The geologic dating of an igneous mass is commonly determined by the age of the latest sedimentary rocks invaded by it. The diorite in this district abruptly truncates all the sediments with which it comes into contact. Thus, in Bonanza Flat beds of Mississippian (lower Carboniferous), Pennsylvanian (upper Carboniferous), and Triassic age are cut. The diorite porphyry invades sediments ranging from Mississippian to Triassic age and the andesite overlies Triassic strata. On the north the extension of the same mass of extrusive rock was mapped by geologists of the Fortieth Parallel Survey as in contact with the "Vermilion Creek group" of the Tertiary (Eocene), and described as follows: "The most important body is that which overlies the Cretaceous and Eocene Tertiary in the neighborhood of Wanship. * * * It is the Vermilion Creek, or the lowest member of the Eocene, with which they are found in contact." [1]

The actual relation of these andesites to the sediments is perhaps nowhere better shown than in the Ontario drain tunnel and also in a small prospect tunnel driven through their contact just beyond the northern boundary of the area mapped. In the Ontario tunnel the lower part of the andesite passes from a normal andesite into a tuffaceous stage characterized by intermingled sediments. This in turn gives way gradually to fine-grained clastic sediments entirely free from andesitic material. The appearance of these transition series strongly suggests that normal sedimentation was interrupted by the deposition in water of materials yielded by volcanic outburst, and that these materials were in small amount at first and increased later until they preponderated. It is not improbable that after the first fall of tuffaceous material into the water the earliest flow also entered the ocean and solidified beneath its surface.

An excellent exposure in the prospect tunnel referred to shows (fig. 2 and Pl. X, *B*, p. 70) the transition from normal andesite through a 3-foot bed of tuffaceous material, then a bed 18 inches in thickness made up of quartz pebbles in a green and gray cementing material of indeterminable orgin, succeeded in turn by 8 feet of gray bedded sandy tuffaceous rock resembling the transition rock in the Ontario tunnel, and this underlain by a crystalline limestone slightly marmarized. It is to be noted that in both these exposures the same transition

[1] Emmons, S. F., U. S. Geol. Expl. 40th Par., vol. 1, 1878, pp. 586, 587.

suggesting deposition in water is present, and that both contacts show the old land surface very steeply inclined to the east. Further, in both tunnels, toward the base of the normal andesite, coal seams occur, the principal one in the Ontario being lenticular and from 2 to 18 inches thick, and in the other tunnel deposits of subangular quartz pebbles also appear. These features suggest time intervals between successive eruptions, during which normal conditions of land surfaces prevailed.

Dates of eruption.—The geologic relations of these igneous masses to sedimentary beds of known age, as briefly stated in the preceding section, tend to indicate that the diorite is not earlier than Triassic, that the porphyry is at least as late as early Triassic, and the andesite is later than the "Vermilion Creek" (Eocene).

STRUCTURE.

The general geologic structure of the formations in this area is that of an anticline whose axis trends roughly north and south, or more exactly somewhat east of north and west of south, and pitches toward the northeast. This broad arch is modified by strong faulting and minor local folding, some of which was very likely caused by intrusions. These several features will be considered briefly. (See Pl. XVI.)

FOLDING.

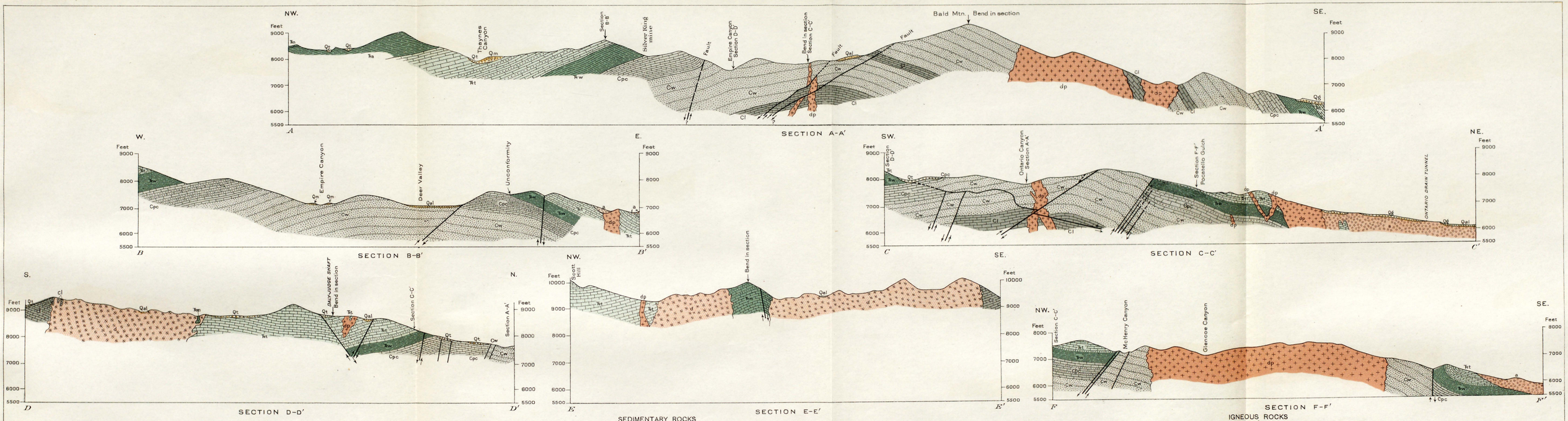
The Park City arch, comprising all the sedimentary formations, embraces the entire area and is the major structure of this district. It is broad and low, the formations composing its flanks dipping gently to the northwest and to the east and southeast. Its axis also descends gently northeastward. The western limb includes the representatives of each formation from the Weber quartzite to the Nugget sandstone inclusive, and forms a structural unit as a monocline. (See Pl. IV, *A*, p 44.) The dip averages 35° N. Just north of Park City the strike of the beds gradually swings around eastward, and at a point northeast of the city the upper formations disappear beneath extensive flows of andesite. All reappear, however, striking southward and passing down the east side of the area to form the eastern flank of the Park City anticline.

On this major fold a few minor folds occur. These are, as a rule, directly traceable to local deformation which at many places has passed the point of folding and caused fractures with faulting. Thus, west of Jupiter Hill the strike of the metamorphosed beds along the south side of the divide gives the appearance from the south of a shallow trough that is broken along the fracture zone opened through the Jupiter mine and marked by the first strong gap in the divide west of Jupiter Peak. Again, crumpling was noted at the head of Thaynes Canyon on the west side, along a strong zone of northeast-southwest fissures.

On the eastern limb the local deformation was apparently greater. At the north, along the east side of Deer Valley Meadow and Frog Valley, two areas show disturbance in strike and dip. North of upper Drain Tunnel Creek, in an angle between faults, the beds are somewhat disturbed, and east and southeast of the head of Frog Valley, in a region which underwent most powerful stresses, the beds are much disturbed, contorted, and broken. Similarly, in the extreme southeast corner of the area mapped, the formations were much strained, as indicated by some crumpling and folding, and the intensity of the force caused some to break. Elsewhere some local deformation, such as crumpling, steep tilting, and irregular contorting, was found in several places; but it is believed that the localities above mentioned embrace the most important instances of folding.

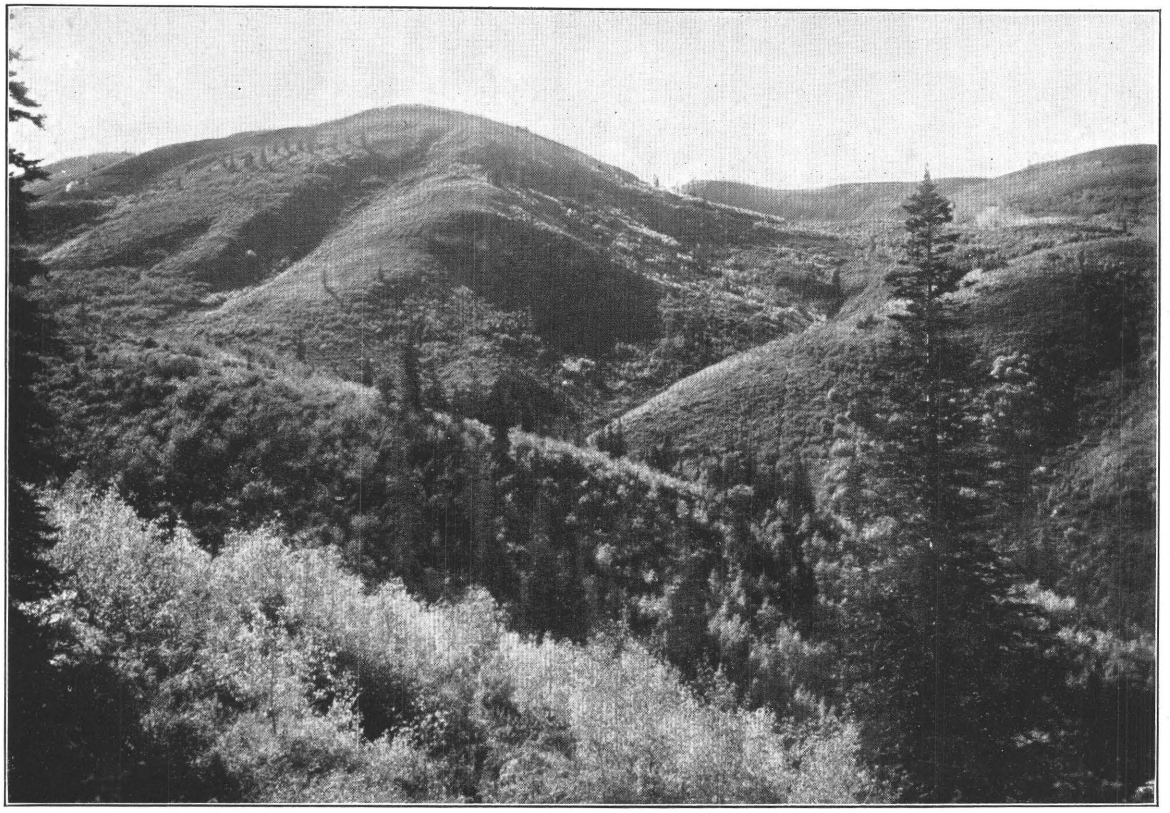
FAULTING.

The continuity of the Park City anticline has been broken by faulting and intrusion. A number of zones of faulting have considerably modified the structure, and six of these deserve special mention. These include on the west side the Ontario-Daly West, Crescent, and Massachusetts fault zones, and on the east the Frog, McHenry, and Cottonwood zones. Careful consideration of the facts at hand fails to reveal any adequate and satisfactory correlation of these important features. Accordingly, it seems safest to consider each of these major zones independently.



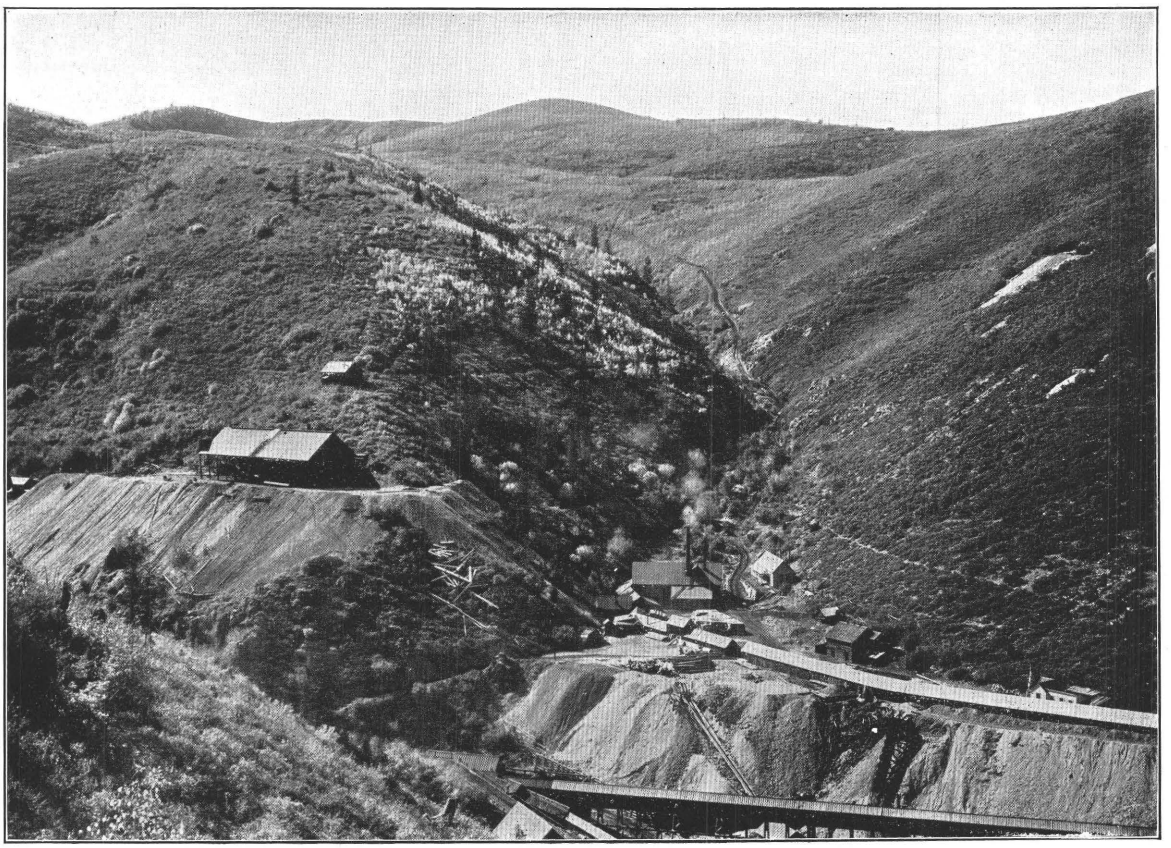
GEOLOGIC STRUCTURE SECTIONS, PARK CITY DISTRICT, UTAH

For position of sections see geologic map, Plate II



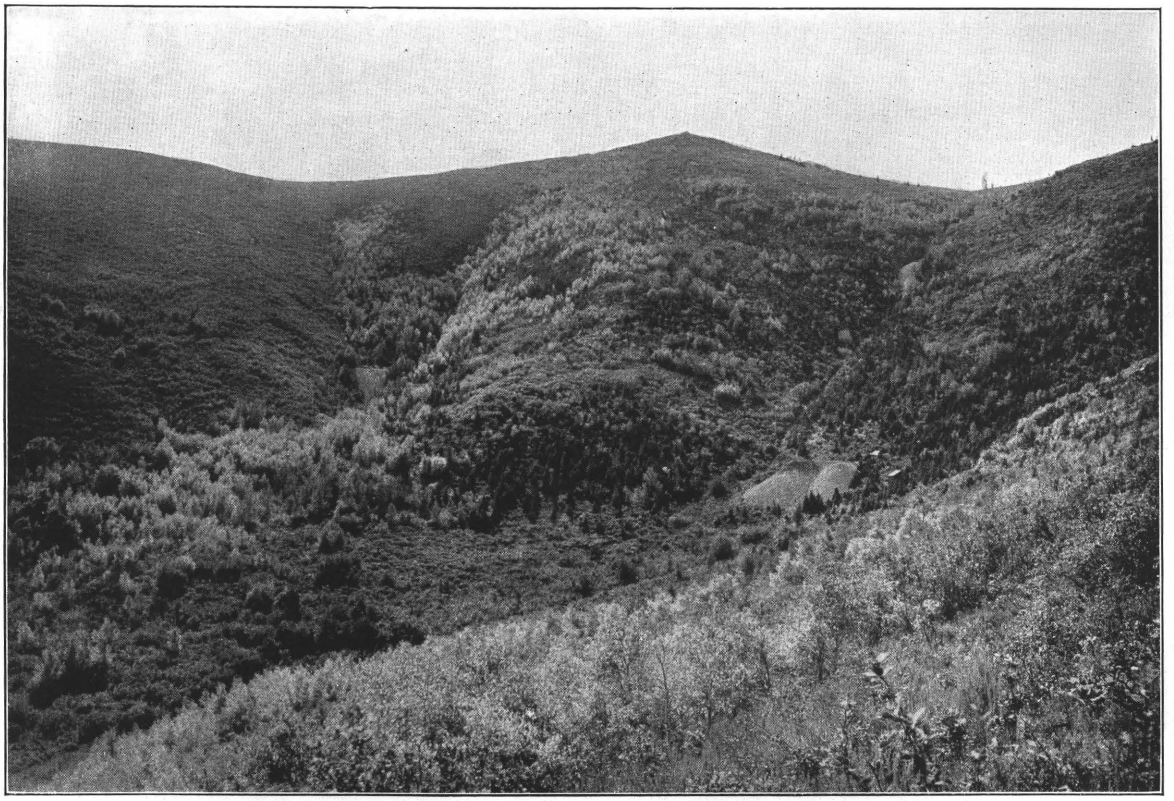
A. CRESCENT FAULT.

Limestone of Thaynes formation at left, truncated on the north and offset to the west, continuing northward in Crescent Ridge, at right background. Looking southeast across Empire Canyon and Walker & Webster Gulch.



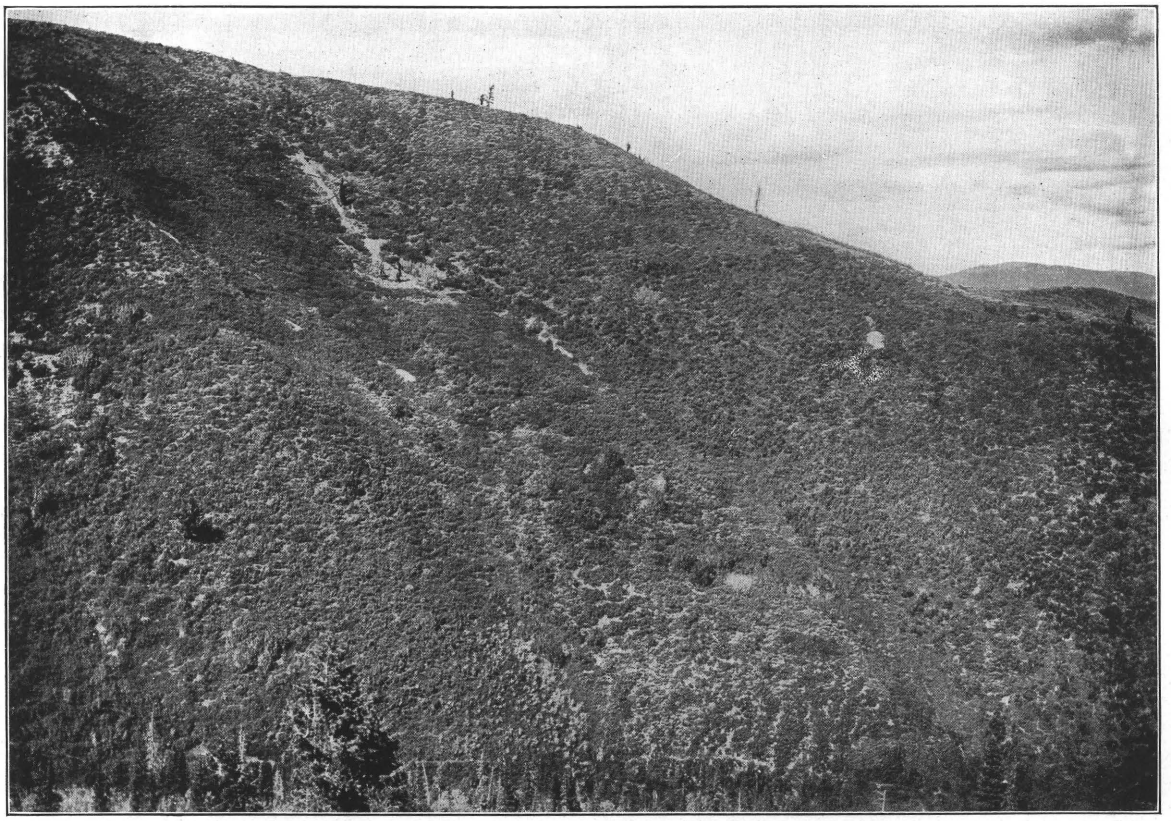
B. MASSACHUSETTS FAULT.

Crossing from Massachusetts shaft, at the left, to the right. Ledges along the lower right-hand side of the gulch are Weber quartzite north of fault. Alliance tunnel in right foreground, Daly-Judge tunnel at left, Crescent Ridge in left background. Looking southwest along Walker & Webster Gulch.



A. MAIN FAULT MARKED BY GULLY AT LEFT AND SUBSIDIARY FAULT BY GULLY AT RIGHT.

Central Spur culminating in peak is on limestone of Park City formation overlooking Woodside shale and limestone of Thaynes formation at left. Looking southeast.



B. GROUND CUT BY SOUTHWARD CONTINUATION OF OVERTHRUST FAULT, NORTH SLOPE OF McHENRY CANYON.

Limestone of Thaynes formation at right; diorite porphyry at left. Looking north. (Compare Pl. II, p. 44.)

FROG VALLEY OVERTHRUST FAULT.

The Ontario-Daly West fault zone measured from its easternmost known point, which is at the surface immediately west of the Parleys Park shaft, to its westernmost known point, which is underground considerably west of the Daly-Judge shaft, is known along its strike for about 2 miles, and in depth 2,000 feet in the Ontario and 2,100 feet in the Daly West. It is a strong zone of fractures ranging from single definite fissures to broad zones of brecciation, and the main Ontario fissure ranges in width from a few inches to a hundred feet. Its prevailing strike is N. 60° E. and it dips toward the northwest at an average angle of 70°.

Structurally it is a great fault on which the hanging wall has relatively dropped. The amount of displacement could not be precisely determined, owing to the absence of a suitable datum in either wall, but according to the best evidence available it was 230 feet just west of the Ontario No. 3 shaft, and appears to have been approximately 350 feet on the Daly West branch. It is later in date than the intrusion of the diorite porphyry and earlier than certain northwest faults. The economic effect of this dislocation, so far as it can be observed, has been a relative elevation of the ore-bearing limestone members. As regards its extension westward, it is highly probable that the gap and decided offset in the main divide above the Daly-Judge shaft are due largely to this great fault zone. Details regarding this and the other fractures are given under the respective mines, and so will not be repeated here.

The Crescent fault zone is known in the Daly-Judge drain tunnel on the east and considerably beyond the crest of Crescent Ridge on the west, thus extending for at least 9,000 feet. Its most prominent outcrop is at the junction of Crescent Ridge and Pioneer Ridge, where the Nugget sandstone and Ankareh shale are dropped into juxtaposition with the Thaynes formation. At this point the trend is slightly north of east and the dip apparently very steep toward the north. To the east the bedrock in the course of this fault is heavily blanketed with glacial material. Beyond, along the west wall of Empire Canyon, the Thaynes formation, equivalent to that on the north side of the fault zone in Crescent Ridge, reappears in prominent bluffs which continue southward. Plate XVII, *A*, shows these bluffs as seen from the east side of Empire Canyon, appearing in the left background and dropping off abruptly at the north; in the background at the right is the gap in Crescent Ridge, to the right of which the corresponding members continue northward. Clearly this is a great fault, and the apparent lateral offset to the west on the north side measures about 3,000 feet. The feature of especial economic interest in connection with this zone is the conclusive evidence it affords that the ore-bearing limestone of the widely separated Silver King and Daly West mines is one and the same formation. So far as known at the time of visit, this fault had not been recognized underground.

Just north of this zone, at the collar of the old Massachusetts shaft, the Massachusetts fault outcrops clearly (Pl. XVII, *B*). It there appears as a well-defined fault between Weber quartzite on the north side and limestone and sandstone of the Park City formation on the south. It strikes N. 70° W. and stands about vertical. Although glacial drift obscures much of the outcrop of this fault, it may be traced on the surface in either direction by isolated outcrops of limestone belonging to the Park City formation on the south and Weber quartzite on the north for a total distance of about 3,000 feet. Underground it is well shown in the Daly-Judge tunnel, and especially in the Alliance tunnel, where it strikes N. 70°–75° W. and dips 68°–70° S. Although not positively identified in the Silver King mine proper, it is believed to have been cut by the King-Alliance connection. In brief, it produced a horizontal offset of about 2,500 feet to the west on the north side. In connection with the Crescent fault, the Massachusetts fault thus forms the north side of an east-west wedge of sediments which has been offset to the west.

In the northeastern part of the district the topography and the distribution and structure of formations give evidence of a great dislocation (Pl. XVIII). Along the east side of Deer Valley Meadow the Park City formation rises abruptly from the flat meadow bottom. At the base of this bluff alluvium prevents observation of the character of contact between limestone and the quartzite. At the north, in the vicinity of the Cincinnati group and northward, is evidence of a north-south fault which has relatively raised the Weber quartzite on the west or moved the Park City formation southward on the east. At the south, along the eastern upper

slopes of Frog Valley, a strong north-south fracture is exposed in a gully with Woodside shale on the east and Weber quartzite on the west. To the south, about 100 feet above the valley, the fault divides and includes a narrow lens of Park City formation. Still farther south the fault continues around the eastern slope of Bald Eagle Mountain, with Thaynes formation on the east and Weber quartzite on the west. This distribution of formations reveals a great and remarkable dislocation which is called the Frog Valley fault. The course of the main fault around Bald Eagle Mountain, curving eastward, indicates that the plane of this dislocation dips toward the west (about 45°), and this suggestion receives further corroboration by the evidence exposed in the Ontario drain tunnel. The fault could not be found south of the bottom of McHenry Canyon, nor could its actual relation with the McHenry fault be observed.

These facts indicate that a great compound overthrust fault occurred here. The west side has ridden up over the east side for many hundred, probably more than 2,000, feet. On the east side of Bald Eagle Mountain, as shown by the fact that the Weber quartzite laps up into contact with the Thaynes formation, the entire Park City and Woodside formations have been completely concealed beneath the wedge of Weber quartzite.

These features may be readily traced on the ground and are well brought out by the topography as shown in Plate XVIII. The economic importance of the recognition of this overthrust fault is that this structure allows the discovery and exploration beyond previously known limits of the ore-bearing Park City formation in regions of favorably fractured intrusion and metamorphism.

Immediately south of the Frog Valley fault lies another great fault, of different type but quite as extensive, known as the McHenry fault. This fault is traceable from the southern head of McHenry Canyon eastward along the north side of the canyon to a point about 2,000 feet east of the Liberty tunnel, a total distance of 1 mile. The actual fault plane appears at the surface where opened just east of the Hawkeye shaft as a zone of intense brecciation striking east-northeast and dipping 45° N. between metamorphic limestone on the north and massive quartzite on the south (Pl. XIX). To the east it is marked by scattered quartzite ledges and a contact between metamorphic limestone of the Thaynes formation and Weber quartzite. Underground it has been opened for many hundred feet in the Lowell, McHenry, and Hawkeye mines. Much of the workings of these mines is inaccessible, but in the portion of the Hawkeye-McHenry which was open at the time of visit this fault was seen to be a zone of intense fracturing and brecciation striking east and west, with a width ranging from a few inches to 170 feet but averaging a few feet. The hanging wall is commonly metamorphic limestone, though for many hundred feet on one level it is quartzite, and in the footwall are quartzite, some metamorphic limestone, and porphyry. At one point well-defined slickensides pitch 45° SW. The general effect of this great fault has been to offset the south side to the east for at least 2 miles.

The last of these master faults lies in the extreme southeastern part of the area, in Cottonwood Canyon, from which it is named. About 4,000 feet southeast of the Valeo mine the eastern wall of Cottonwood Canyon is interrupted by a low saddle. This topographic feature marks a fault contact between Weber quartzite on the north and Woodside shale on the south. It has been followed along a sinuous east-west course for about 4,500 feet. Its effect has been to shift the formation on its north side toward the east for about 4,000 feet. It may thus be regarded as a smaller companion fault to the McHenry, the two inclosing between them a wedge which appears to have moved relatively eastward.

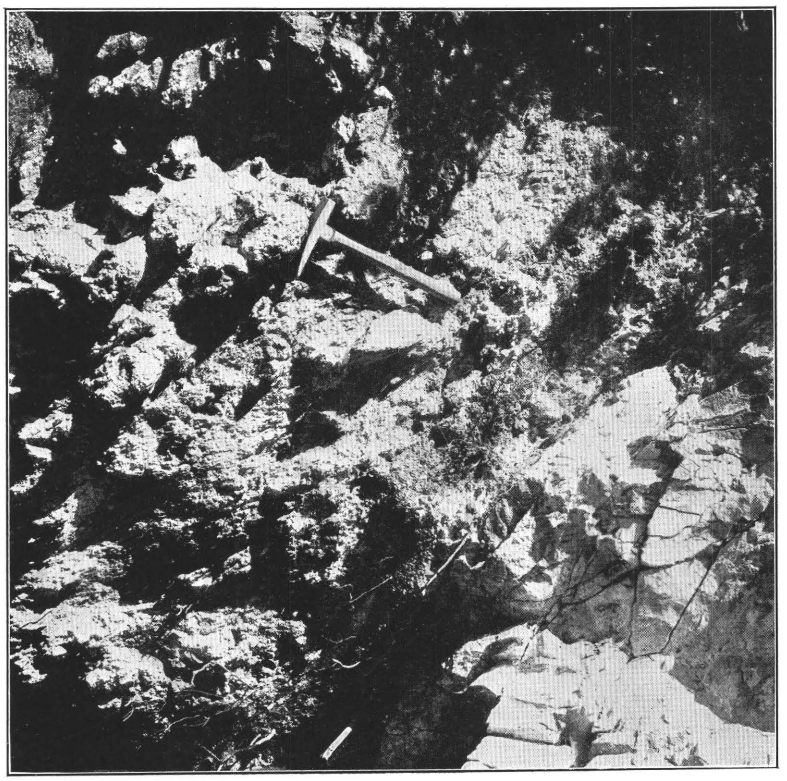
DEFORMATION BY INTRUSION.

The injection of masses of the volume of the great Clayton Peak body of diorite porphyry into the mass of sedimentary rocks which had previously occupied this entire space obviously tended to deform these sediments intensely. Whether the engulfing and absorption of portions of the invaded sediments by the intrusive magmas was large or small, the compressive force exerted on the sediments was, even if rated at its minimum, very great.

The introduction of the Clayton Peak mass, which probably entered the basal portion of these sediments only, without reaching the surface, doubtless domed the overlying Triassic and Jurassic sediments.

A. SLOPE TRAVERSED BY FAULT.

Marked by ledges of quartzite in footwall under limestone of Thaynes formation on north. Looking east-northeast, down McHenry Canyon. Hawkeye dump in left foreground; Liberty tunnel at right.



B. FAULT ON SURFACE.

Immediately east of Hawkeye shaft, between fractured massive limestone in hanging wall and brecciated Weber quartzite and limestone underneath. Looking west.

McHENRY FAULT.

The invasion of the Carboniferous formations by diorite porphyry magma, apparently forcing its way irregularly northeastward, would seem to have been accomplished under very high pressure and naturally produced corresponding deformation. Instances of such deformation directly traceable to this cause are to be seen in several places. Two miniature examples will suffice to prove the existence and to show the nature of this deformation, and thus point the way for detecting similar effects on a larger scale.

In the Silver King mine, on the 1,100-foot level, the main crosscut south has exposed tongues of diorite porphyry extending upward into calcareous sandstone. Aside from the metamorphic influence of this intrusion, which is considered under "Genesis of the ores" (pp. 128–129), its structural effect consisted in crushing the rock ahead, in fracturing it, and in opening fissures. (See Pl. XXIII, *B*, p. 104.) Similarly a knob or miniature laccolith exposed on the north side of the main road just west of the West Quincy mine reveals flexing of beds, crushing, shattering, and fissuring, as shown in figure 3, which is reproduced from an exact sketch.

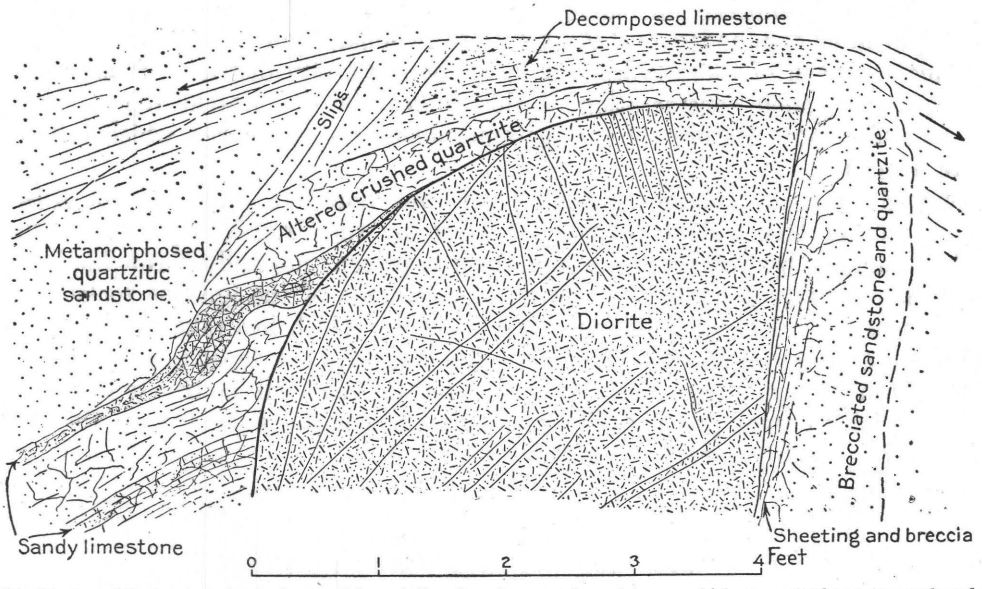


FIGURE 3.—Dioritic laccolith doming, fracturing, and brecciating limestones and sandstones, which are notably metamorphosed. Bonanza Flat west of West Quincy shaft.

In precisely the same manner as these small masses acted in miniature the great intrusive bodies may reasonably be supposed to have acted on a proportionately larger scale. Broad observation reveals facts which tend strongly to indicate that such has been the case. Thus, the area of the Frog Valley overthrust fault and the McHenry and Cottonwood faults may be mentioned. To recapitulate, a wedge a mile long north and south and 2,000 feet thick, comprising the lower formations on the west, is thrust up over the younger beds on the east until the Weber quartzite laps over the Park City and Woodside formations against the Thaynes formation, and to the south a block averaging 2 miles in width north and south and made up of sedimentary formations from the Weber to the Thaynes and intruded porphyries has moved bodily eastward at least 2 miles.

The evidence indicates that a series of intrusive bodies extends in a narrow east-west belt across the Wasatch Range; that they invaded the Park City area from the west, breaking upward and eastward; that those in this area are thus the highest and easternmost members; that at the east end and ahead of this chain of intrusives the formations are thrust eastward, one formation completely over the next two normally overlying ones; and that directly in the path of the intrusives the formations have given way chiefly on two great faults and have moved relatively eastward at least 2 miles.

Finally, the occurrence of horses of limestone of Pennsylvanian and of lower Mississippian (Madison) age in diorite porphyry in the southeastern portion of this area affords evidence

of the most extreme instance of deformation by intrusives. In that vicinity, entirely inclosed in porphyry, are blocks of limestone from a few feet up to 1,000 and even 2,000 feet in length. Some of these blocks may be safely correlated, by their relative position with certain near-by limestone members intercalated in the Weber quartzite. Fossil evidence, in the opinion of Dr. Girty, shows the age of some to be lower Weber (Pennsylvanian) and of others to be Madison (Lower Mississippian). In other words, the horses pretty clearly belong lower by several thousand feet than the lowest sediments outcropping in their normal sequence in this region. Thus the conclusion follows directly that the intrusives in making their way into their present positions tore away portions of lower-lying formations and floated them up for thousands of feet.

METAMORPHISM.

GENERAL TYPES.

Metamorphism comprises all changes whatsoever that rocks undergo. The chief types of metamorphism as expounded by Lindgren [1] are regional, hydro, contact, and hydrothermal metamorphism. Each of these types is seen in the Park City district. It is not the aim to enter upon an extended consideration of this subject in the present report, but rather to describe concisely those features of the metamorphism in this district which bear essentially on the ore deposits.

Accordingly regional metamorphism, which was noted in only two localities—on the divide near Jupiter Hill and on a knob traversed by the Frog Valley overthrust—may be neglected. Similarly hydrometamorphism, which is present normally throughout the district, being more particularly noticeable in certain constituents of the igneous rocks, need not be especially discussed. Contact metamorphism, however, which has taken place extensively in this region and appears to have been directly connected with ore deposition, is described below. Hydrothermal metamorphism, which occurred in certain veins will be briefly treated. Finally, those changes which were produced by the action of surface waters upon the primary ore deposits may be properly considered in this connection.

CONTACT METAMORPHISM.

IMPORTANCE AND EXTENT IN THIS REGION.

The term contact metamorphism, as used in the following description, denotes those changes which take place in sediments in the zone adjacent to an intrusive rock. These changes vary according to many factors but are generally greatest in calcareous and least in siliceous rocks. This kind of metamorphism produces a certain characteristic series of secondary minerals, which are accordingly known collectively as contact-metamorphic minerals. The association of minerals of this known origin with ore minerals thus establishes the mode of origin of those ores. Hence in the study of a mining district the sure determination of the existence of contact metamorphism is important.

As previously stated, a chain of intrusives transects this portion of the Wasatch Range, breaking through all sedimentary formations from pre-Cambrian to Triassic, inclusive. In the immediate area under survey (Pl. II, p. 44) the formations from the Weber (Pennsylvanian), to the Ankareh (Triassic), including some of calcareous and others of siliceous character, have been intruded. Reconnaissance work along this zone of intrusives, both in and near the Park City district, has revealed localities in which the phenomena of contact metamorphism attain most exceptional development. These are about the heads of Big and Little Cottonwood canyons, Snake Creek, and American Fork. As these localities, though just outside of the area mapped, are parts of a single province, it seems best to describe briefly the broader features of contact metamorphism observed in this whole area rather than restrict the discussion to the less instructive part which falls within the limits of the Park City district.

[1] Lindgren, Waldemar, Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 123.

In general, the Clayton Peak stock of diorite at the southwest breaks eastward through the Ankareh and Thaynes formations to the Woodside shale. Beyond, the diorite porphyry, continuing eastward, breaks across the Woodside and Park City formations down to the Weber quartzite. In the southeastern portion of the area blocks of limestone are included in this diorite porphyry as horses (fig. 4). These, according to fossil evidence, lie normally below the lowest beds outcropping in this district and thus were engulfed and floated up by the ascending magma.

As the contact zone between the series of intrusives and the sedimentary formations cut by them stands up as a lofty rugged ridge, the main divide through the district, it is evident that these formations have undergone changes along this zone which render them more resistant to weathering. The metamorphism has so far modified their character that the formations over considerable areas can not be positively recognized. Along most of the zone, however,

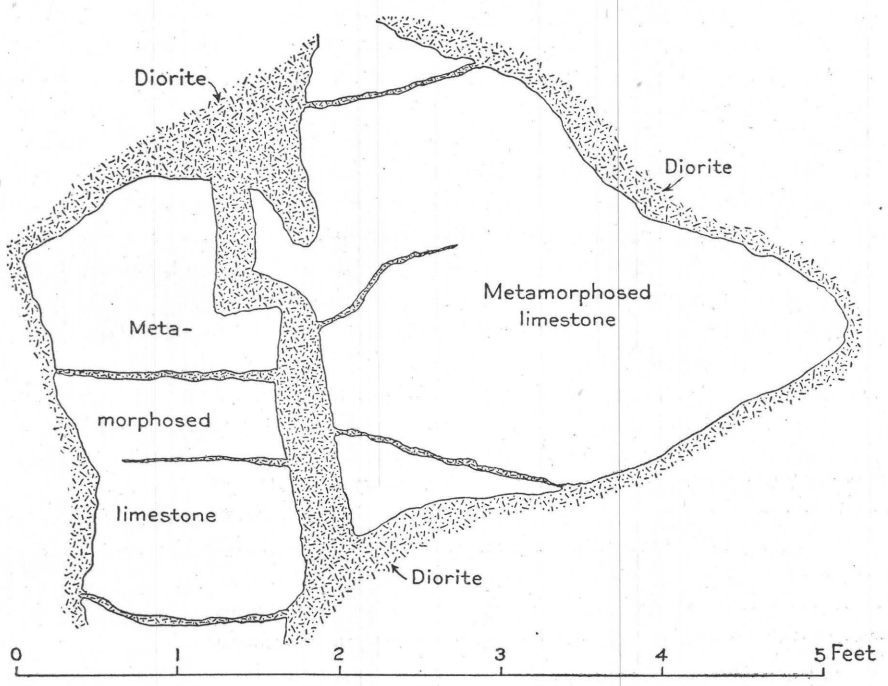


FIGURE 4.—Horses of limestone in diorite, showing development of contact-metamorphic minerals. Bonanza Flat near Jones shaft.

the formations and in places even the members of the formations can be followed from the unaltered portion to the intrusives and the changes which have taken place toward the contact may be observed.

METAMORPHISM IN LIMESTONE.

Broadly speaking, the calcareous formations undergo the greatest alteration. At the contact metallic sulphides were noted in certain places, outside of which lies coarsely crystalline marble; next beyond that is a wide and variable belt of altered limestone characterized by the predominant development of certain silicates, and this gradually gives way to normal unaltered limestone.

Perhaps the most perfect example of sulphide formed along a contact was that observed in the Silver King mine, 1,100-foot level, on the south crosscut at the fork of the drift west. A band of pyrite about half an inch thick there lay along the contact between diorite porphyry and a calcareous bed in a gangue of calcite (Pl. XXIII, *B*, p. 104). In the Daly West mine also a body of rich sulphide ore was observed in metamorphic limestone immediately overlying diorite porphyry.

Coarse marble outcrops along the main "contact divide" adjacent to the Jupiter gap and immediately west. To the south lies the main diorite body and on the west are small dikes of diorite. This mass of marble, though not extensive, is the largest observed in the district.

Marble also occurs along the divide overlooking the head of Thaynes Canyon from the west, with intrusives not far to either side; along the main divide southwest from the Quincy shaft and adjoining a large intrusive mass of diorite porphyry; at the east end of Bonanza Flat in horses in diorite porphyry; and on a knob southeast of the head of Frog Valley. It is noteworthy that each of these areas of marble also lies near some strong fissure. Only in the Frog Valley locality, however, is there any reasonable doubt as to the marmarization being due to the influence of intrusives. The complete metamorphism of limestone of the Park City formation to coarse white marble at a point comparatively remote from any considerable intrusive body, but along the great Frog Valley overthrust, strongly suggests that this metamorphism was dynamic and due to the overthrusting.

The next succeeding zone in the main contact zone is characterized by contact-metamorphic silicates and varies greatly in width and character. An attempt has been made to indicate roughly on the geologic map (Pl. II, p. 44) the area of this zone; in general it extends back from the main contact for many hundred feet. The effects in the limestone of the Park City formation are not well exposed along the main contact divide, as exposures of that formation there are singularly meager. The Thaynes formation, however, occupying the greater part of the divide, is widely found in its metamorphic state. Perhaps the best exposure of metamorphosed limestone of the Thaynes formation is in the serrate craggy portion of the main divide which overlooks the amphitheater about the southwest head of Empire Canyon south of the Daly-Judge shaft. It is also well exposed along the divide to the west on either side of Jupiter Hill and in and adjacent to Scott Peak. In general this limestone in the zone of metamorphism becomes light greenish gray, with certain members of an olive-green color.

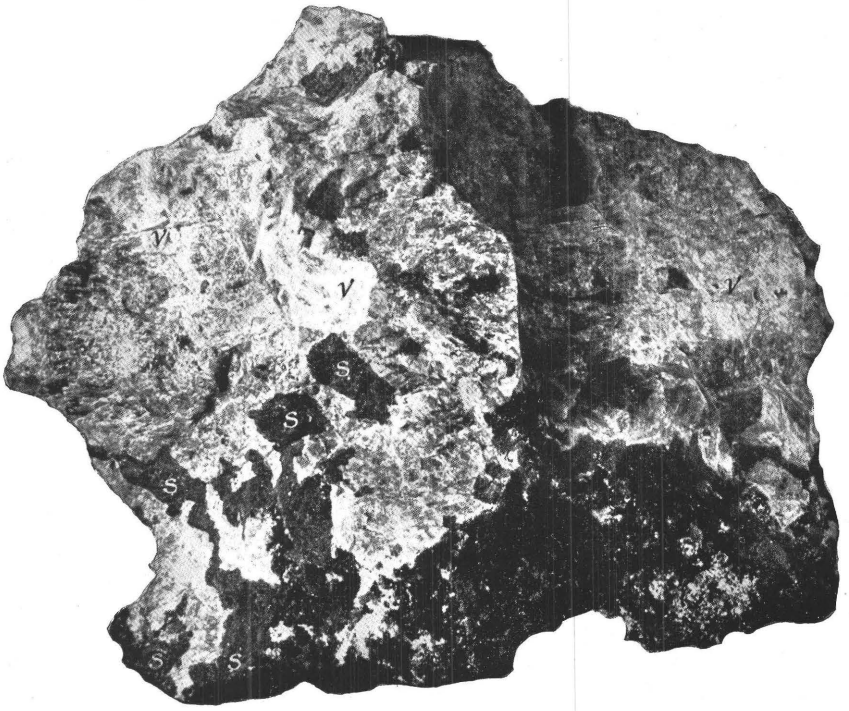
The minerals developed by this metamorphism comprise most of the regular contact-metamorphic series. Probably the most common of these is epidote. Brown and green garnet are also found, generally in massive form but here and there partly crystallized. Large masses of vesuvianite were discovered at one point intergrown with spinel (Pl. XX, *A*). Along this same contact minute crystals of chabazite are scattered thickly over the surface of the metamorphosed rock. Augite is abundant in many places. Mica is present, both biotite and muscovite, but chiefly the latter. Plagioclase feldspar, probably albite, was also detected.

In some places these minerals occur in massive form, composing the entire rock, and in others they lie in a matrix of calcite. Associated with them are the metallic minerals specularite, sphalerite, pyrite, chalcopyrite, and magnetite. These are intergrown with the metamorphic silicates in such a way as to demonstrate their contemporaneous origin.

METAMORPHISM IN SHALE.

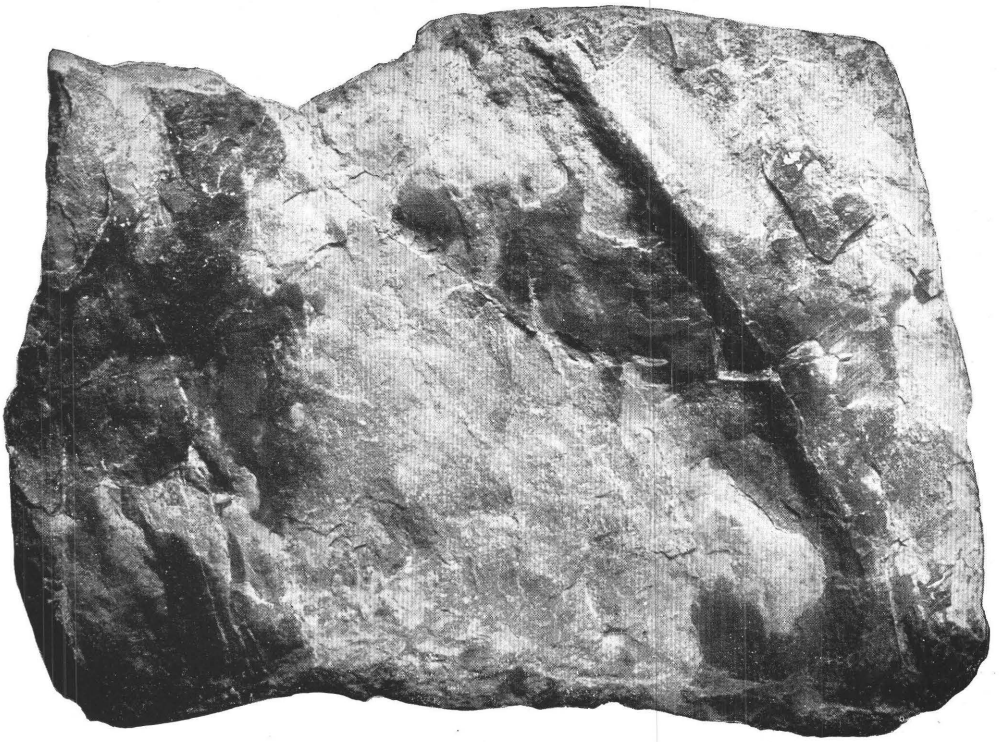
The contact metamorphism of shale is quite as pronounced as that undergone by limestone, though less varied and perhaps less extensive. The Woodside shale occurs in the main divide south of the Daly West shaft. The Ankareh shale outcrops just west in the main divide above the Daly-Judge shaft, extending eastward above that shaft, and also in Jupiter Hill.

Locally the entire mass of shale, which is elsewhere red, appears in this contact zone with an olive-green color. This is well shown on the slope above and to the west of the Daly-Judge mine. In other places, as on the divide above and west of the diorite tongue in the Daly-Judge gap, a dense black siliceous rock which is practically a hornstone seems to have replaced shale. Again, as in Jupiter Hill, red shale has been metamorphosed to a flinty tough rock of dark-red baked-brick color banded and spotted with olive or leek green. Both the olive-green shale above the Daly-Judge and the maculated rock in Jupiter Hill may be traced back from the contact into normal red shale. In the former locality, about the head of Morgan Valley, individual members may be traced from the green to the red and transitions are found which show red spots in a green base and green spots on a normal red shale (Pl. XX, *B*). On microscopic examination this characteristic alteration is seen to be due chiefly to the development of epidote. There also appears to be an increase in quartz. In the metamorphism of the coarser siliceous rocks, as sandstone, the apparent change is still more simple and less extensive. The impurities of the matrix are driven off and the silica, doubtless with additional magmatic silica, is united with the quartz grains to form a solid mass of quartzite.



A. SOLID MASS OF VESUVIANITE (*v*) AND SPINEL (*s*).

Developed in semicrystalline form in limestone adjacent to south contact of Clayton Peak diorite stock. One-half natural size.



B. RED SHALE BLOTCHED WITH OLIVE-GREEN AREAS, CHARACTERIZED BY EPIDOTE.

Contact zone west of head of Empire Canyon.

CONTACT-METAMORPHIC PRODUCTS.

A. MARMARIZED AND SERPENTINIZED BRECCIATED UNDIFFERENTIATED CARBONIFEROUS LIMESTONE.

B. SERPENTINE AND MANGANESE IN METAMORPHOSED LIMESTONE ADJACENT TO INTRUSIVE ROCK AND FISSURES.

From 1,500-foot level east of No. 2 shaft, Ontario mine.

METAMORPHIC PRODUCTS.

HYDROTHERMAL METAMORPHISM.

Alteration by hot waters produces other metasomatic changes. These waters more commonly follow fractures and move in a generally ascending course. It has been clearly shown that in numerous well-known localities they have arisen from deep-lying molten masses as one of the "after effects" of intrusion. Consequently this type of metamorphism takes place chiefly along fissures. It is characterized by the formation of quartz, sericite, and pyrite, and sometimes produces other minerals.

This type of metamorphism is present in this district along certain major zones of fracture, especially adjoining extensive bodies of intrusive rock. It can hardly be regarded as being so important in this district as in some others, such as Bisbee, Morenci, and Cananea. Thus, along the lode on which the Ontario, Daly West, Daly, and Daly-Judge mines are situated quartz occurs in fragments in the breccia, cementing brecciated portions and replacing wall rock. This is well shown in the Ontario mine, on the 1,500-foot level west of the No. 3 shaft; in the Daly West, on the 1,400-foot level west of the shaft; and in the Daly-Judge, in western fissure workings on the 1,200-foot level. In some of the Daly West stopes on lode ore the seams, which abound in the barren portions between the ore bodies, are walled and marked with quartz clearly of this origin (fig. 8, p. 117). At the extreme west end of the mine, adjacent to the great diorite mass, aggregates of large quartz crystals have been found. In the Ontario, on the 900-foot level, on the 1,500-foot level between shafts 2 and 3, and on the 1,700-foot level, considerable quartz and some rhodochrosite and pyrite occur as gangue mineral in veins. On the 1,500-foot and 1,700-foot levels of the Ontario mine, quartzite and porphyry breccia in the fractured zone and porphyry in the walls show pyritization characteristic of hydrothermal metamorphism. Similarly, on the 1,700 and 2,000 foot levels of the Ontario and in the Daly West mine the porphyry shows bleaching, which under the microscope is seen to be to a large extent due to sericitization.

Some silicification and pyritization are seen elsewhere, as in the Comstock and American Flag mines, but in comparatively minor degree.

On the 1,500-foot level of the Ontario mine, east of No. 2 shaft, considerable coarse contact-metamorphic marble is found at one point in the vicinity of both coarse intrusives and fissures. Serpentine is plentifully developed in the marble, and spots of a dusty black material (pyrolusite) occur (Pl. XXI, *B*). Mica is also altered to chlorite and probably some to sericite. It is difficult to determine how much of the development of these secondary minerals is due to hydrothermal metamorphism and how much to hydrometamorphism, but some was clearly produced by ascending hot waters.

SUPERFICIAL ALTERATION OF ORES.

The alteration of the primary ores by surface waters falls strictly under the head of metamorphism, and, accordingly, will be briefly described at this point rather than under "Genesis," as a recent stage in the formation of the ores. The oxidation reaches a maximum depth of 1,700 feet, but averages approximately 600 or 700 feet. The principal feature of interest which has been made out is the complete oxidation of galena-tetrahedrite ores at a depth of 1,200 feet to hydrous antimonate of lead (bindheimite).

LEVEL OF GROUND WATER.

Ground water was encountered near the surface in the early days, and through mining operations has been lowered many hundred feet. Thus it is reliably reported that a great flow of water was struck at a depth of 66 feet in Ontario ground, and as sinking progressed each new level opened extensive new flows. The quantity of water became so great and the cost of handling it so high that a drain tunnel was driven at the 600-foot level. The enormous quantity of water which was opened at lower levels could not be economically handled through this tunnel. Accordingly, a deeper drain tunnel was driven at the 1,500-foot level. At the time of visit water was rising above the 2,000-foot level and the 1,700-foot level to the 1,500-foot level, whence it issues constantly in great volume.

Exploration in the early days in adjacent ground on the east showed an immense amount of ground water present at comparatively shallow depths. Work in the Hawkeye, Lowell, McHenry, and Parleys Park mines was stopped repeatedly by uncontrolled water. After the deeper tunnel had drained this ground, no further serious difficulty from water was experienced.

The Daly-Judge (old Anchor) in sinking in fairly early times close to the divide, where the water level naturally stood high, met baffling flows of water. Eventually a drain tunnel became necessary here and a long tunnel was driven from Empire Canyon to intersect the Daly-Judge shaft at a depth of 1,200 feet.

In view of the great outflow through these drain tunnels it was not surprising that later, when the Silver King undertook deep mining, the ground-water level was not encountered. In fact, it is reliably stated that in sinking from the collar to the bottom of the 1,300-foot shaft not a drop of water was pumped, and that water had to be carried into the mine for use in drilling. At the time of visit this mine was entirely dry throughout.

In ground adjoining the Silver King on the northwest, the Silver King Consolidated Co. sunk a shaft in red shale which encountered a great flow of water. This, however, was clearly a local occurrence resulting from the well-known habit of shale to retain water.

Evidently the ground-water level in this district was high. From the main divides it descends beneath and accordant with the surface and reappears at the master drainage depressions. This level, after the escape of enormous quantities of water, has been lowered about the deeper workings to a depth of 1,500 feet and has been modified accordingly in tributary ground. Further particulars are given under "Drainage and ventilation" (pp. 24–26).

EXTENT AND CHARACTER OF ALTERATION.

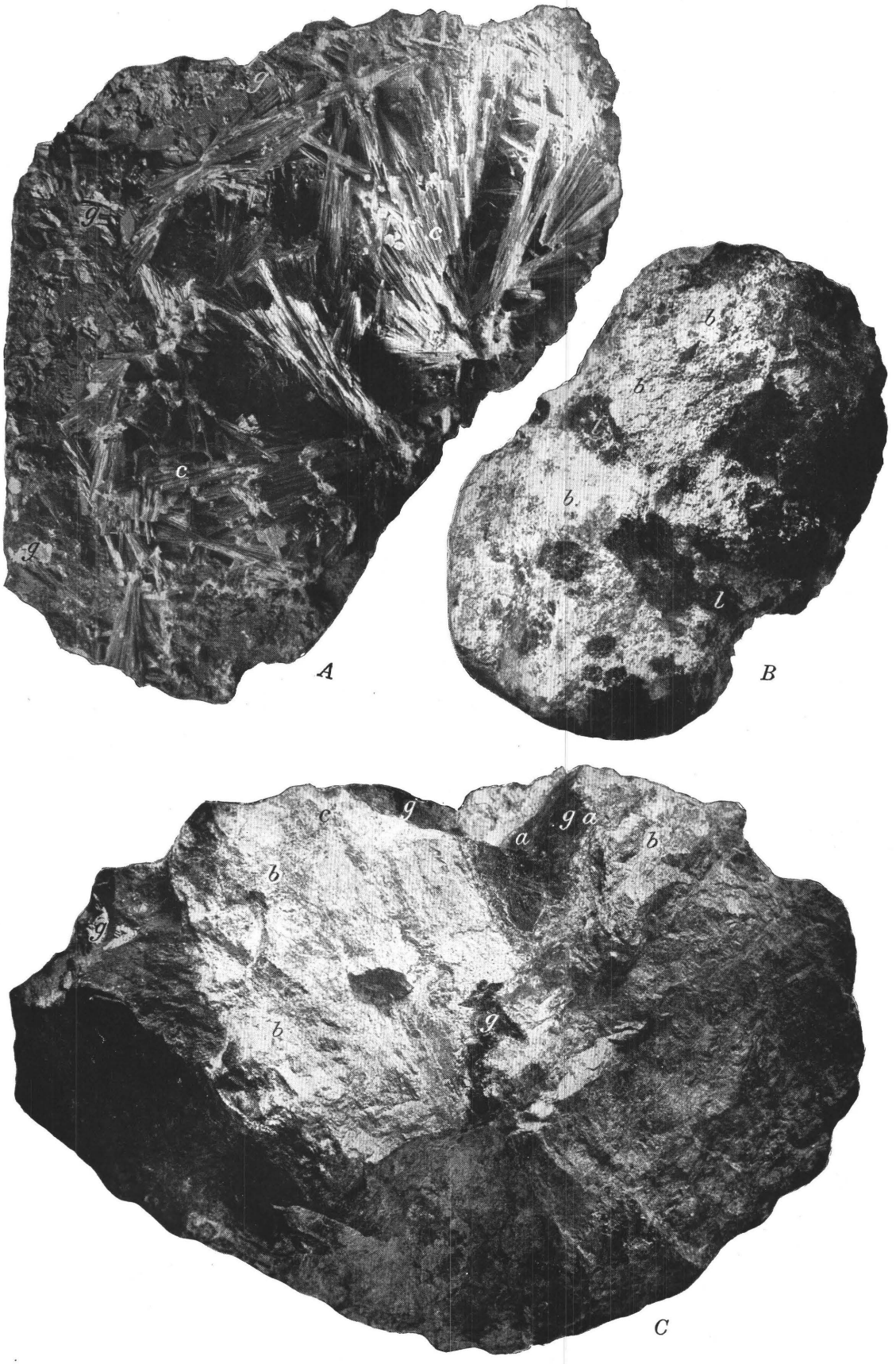
The bedded ores, best exemplified in the Silver King and Daly West mines, are found to be normally oxidized to depths of 500 to 800 feet. Thus the Quincy bedded ore was thoroughly oxidized to a point just above the 300-foot level, where sulphides began; considerable carbonate ore was seen on the 400-foot level, however, and some at a depth of 570 feet.

Below, in the Daly West, the highest workings at the time of visit were 630 feet below the collar of the shaft. Stopes at that depth showed cores of sulphide inclosed in carbonate and oxide ore. Beds of ore below this were entirely sulphide and continued so to the 900-foot level, the deepest working on the bedded ore.

In the Silver King mine the bedded ore at the 750 and 800 foot levels was essentially carbonate, though some sulphide was admixed. Below, on the 1,000-foot level, where the "gash" and bedded ore bodies come together, the latter was entirely sulphide. Yet on the 1,200-foot level west a bed of ore was completely oxidized, but as this took place along a fissure, it was not normal.

The alteration of ore along fissures varies most. The Ontario lode, being opened from the surface to a depth of 2,000 feet, affords an excellent scale, though unfortunately so much of it in the upper older portion of the mine was inaccessible that the data obtained were very incomplete. Some of the croppings of the lode showed galena, and on the Union (100-foot) level west considerable seams of galena were observed. The outer parts of "spur" veins on the 1,000-foot level were composed of carbonate ore, and some carbonate ore was seen on the 1,700-foot level. In general, however, it is reliably reported that oxidized ores were richest between the 600 and 750 foot levels and that carbonate ore continued some distance below, though leaner and rapidly decreasing. On the 1,500-foot level, which was being stoped at the time of visit, the ore was essentially sulphide.

In the Silver King a unique occurrence was observed of oxidized lead ore at a depth of 1,200 feet. Here a bed of coarse galena ore with tetrahedrite, about 3 feet thick, dipped gently (15°) northward between rusty ferruginous walls of calcareous sandy rock, and was cut and clearly deformed by a N. 70°–75° E. fissure dipping 75° NW. (See fig. 5.) This bed for several feet back from the fracture had been altered to an earthy yellow mineral, which on analysis proved to be an antimonate of lead, probably bindheimite.



A. SHEAVES OF ACICULAR CRYSTALS OF CERUSITE (*c*) UPON A BASE OF GALENA (*g*).

B. ORE COMPLETELY ALTERED TO FINE YELLOW POWDERY BINDHEIMITE (*b*) WITH MASSICOT (?) BLOTCHED WITH LIMONITE (*l*) AND MANGANESE.

C. ORE SHOWING LESS ADVANCED STAGE OF ALTERATION, WITH SMALL CORES OF GALENA (*g*) ENCIRCLED BY BANDS OF ANGLESITE (*a*) AND SMALL AREAS OF CERUSITE (*c*) IN MAIN MASS OF FINE ORANGE-YELLOW OXIDATION PRODUCT BINDHEIMITE (*b*).

PRODUCTS OF ALTERATION OF LEAD ORE.

As to the nature of the changes which took place in the production of the rich lead and copper oxide and carbonate ores, little of interest was discovered. Accordingly, it will suffice to mention briefly the characteristic alteration products. The rich bedded ore in the Silver King and great blocks of slightly altered galena ore from the "gash" at a depth of about 1,100 feet afford complete epitomes of the succession of changes.

The primary lead ore (lead sulphide, galena) alters to anglesite and this to cerusite (Pl. XXII). Further alteration results in a brownish-yellow, waxy amorphous mineral, which eventually passes into a dusty bright-yellow material. This appears to be a mixture of lead oxide, probably massicot, and various complex inseparable alteration products. Chief among these, as shown by chemical work, is a compound of lead and antimony apparently derived from both galena and gray copper, which is probably bindheimite.

Copper first becomes significant with the appearance in the ores of tetrahedrite, though the pyrite is somewhat cupriferous. Critical search and the examination of large masses of absolutely unaltered sulphide ore made up of coarsely cleavable galena and massive gray copper fail to reveal any evidence for secondary origin of this rich copper mineral and thus tend to

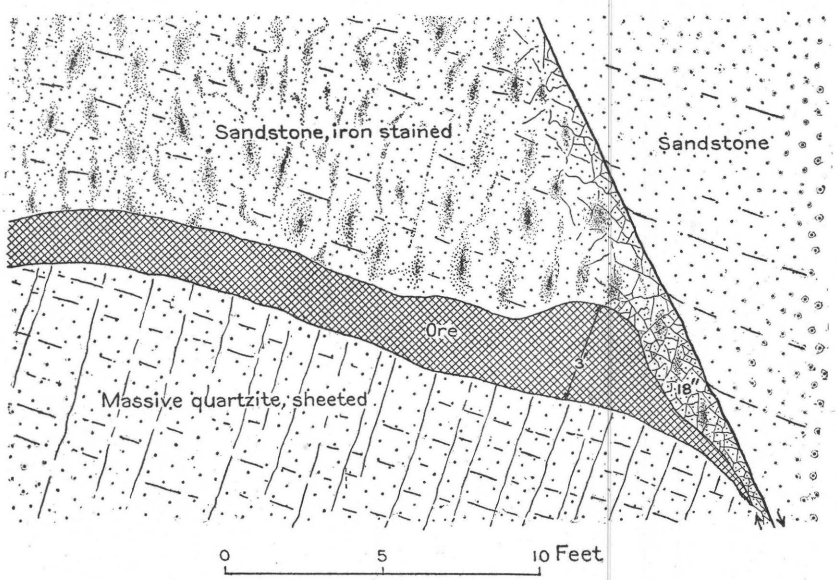


FIGURE 5.—Bed of rich cupriferous galena between siliceous sediments truncated by N. 70° E. fault. Ore dragged, brecciated, and thoroughly altered adjacent to fault zone, becoming almost entirely bindheimite. 1,200-foot level west, Silver King mine.

show that the tetrahedrite is primary and contemporaneous with the intergrown galena. Specimens of this ore from the Silver King and Daly West mines, which have been partly altered, show pits and cavities which are crusted with the alteration products of these sulphides. Coating cores of the sulphide are the blue and green carbonates azurite and malachite.

Silver was not found in sulphide form nor was it recognized in oxidized products. It is known to occur in the galena and in pyrite and sphalerite. Gold was not observed, though proved present by assays. The ore was richest where manganese was abundant and apparently the gold ran highest where the ore was most altered and decomposed.

GEOLOGIC HISTORY.

The main events in the geologic history of the middle Wasatch have been stated in reviewing the general geology of that region, and the detailed study of the Park City area, which lies within that larger region, affords additional facts.

Early Paleozoic time is not represented in the rocks exposed in the immediate vicinity of Park City. The oldest deposits, the great Mississippian limestones, indicate an extensive and prolonged depression such as is favorable to an accumulation of calcareous sediments with but little admixture of detrital material. The source of such material must have been remote

or the supply very meager, and the conditions sustain the inference of fairly deep water and a considerable distance from shore line. The occurrence of siliceous and quartzitic beds in the upper Mississippian, however, is evidence of a gradual change from these conditions to such as permitted the enormous accumulation of sands formed in Pennsylvanian time (Weber quartzite) and this change could hardly have been effected except through an elevation of the land which brought the shore line so near to this area that terrestrial waste reached it in quantities. This condition also was not maintained uninterruptedly, as is shown by the earthy and calcareous beds which traverse this great formation, mainly arenaceous in its character.

The transition from Mississippian to Pennsylvanian time, though apparently gradual, was accompanied by a rather abrupt and complete change in the organic remains, and even the lithologic sequence, at least in certain sections, shows a rather sharply defined change. Whether the transition from Pennsylvanian to Permian (Park City) time was gradual or was marked by disturbances and erosion of the underlying Weber is not clearly shown by data obtained in the Park City district, but the evidence tends to indicate a normal sedimentary transition. The conditions which prevailed during the closing part of Permian time, as shown by the alternating limestone, sandstone, and shale of the Park City formation, were at different stages those of sea bottom, shallow shore bottom, and exposed shore with mud flats.

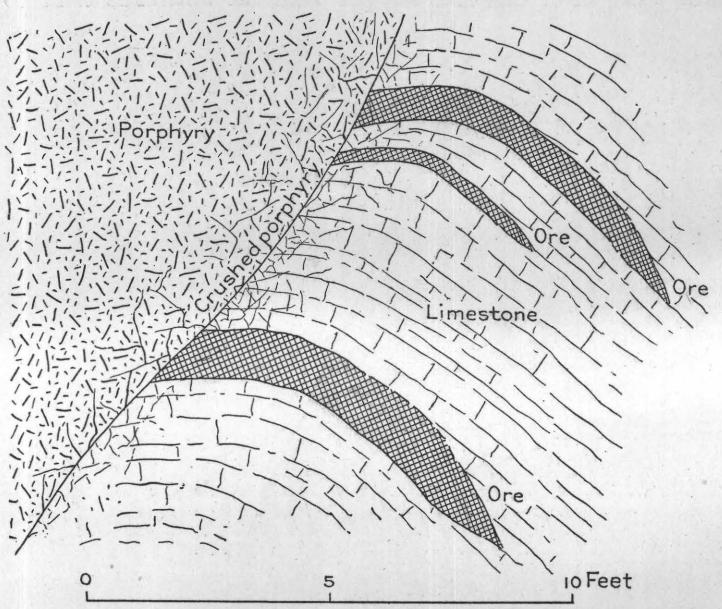


FIGURE 6.—Bedded ore in limestone adjacent to intrusive, cut by fault of postintrusive and postmineral date, Kearns-Keith mine.

More constant but apparently not very different terraqueous conditions began in early Lower Triassic time (Woodside shale). In the middle Lower Triassic (Thaynes formation) the waters were temporarily clearer and the land more remote and in the upper Lower Triassic (Ankareh shale) the shore was again near this region. That any very important oscillations in level occurred during the Lower Triassic may be doubted, though numerous minor ones are suggested. The Woodside shale, including relatively little sandy or calcareous material, is contrasted with the Thaynes, which consists mainly of both. There seems thus to have been a gradual if irregular approach of the shore in the Lower Triassic, terminating in late Triassic or early Jurassic time in the deposition of a great thickness of a coarse and in many places cross-bedded sandstone (Nugget). This in turn was followed by a depression which permitted the deposition of fine-grained thin-bedded limestone (Twin Creek) in Jurassic time.

An uplift at the close of Park City time, indicated by the change from calcareous to shaly sediments, was accompanied by a biologic change of pronounced character, with an almost complete extinction of Paleozoic types of life, at least in this region.

A slight elevation at the close of the Jurassic restored the tract north of this district to sea level, and probably this district also, although the detrital sediments persisting at the north have since been removed from the Park City area. At the close of Cretaceous time, in connection with the general uplift and development of the Wasatch Range, the Park City area was in all probability greatly elevated.

Contemporaneous with these orogenic activities was strong fracturing and faulting, some of it probably in a northeast-southwest direction. After the Carboniferous period and particularly after this Cretaceous elevation, there was active and extensive erosion. In connection

A. CONTACT BETWEEN WEBER QUARTZITE AND OVERLYING LIMESTONE OF PARK CITY FORMATION.

Contact, which is apparently conformable, is marked by head of pick. On 900-foot level, Daly West mine. Looking east.

B. TONGUES OF DIORITE PORPHYRY EXTENDING UPWARD INTO CALCAREOUS BEDS, METAMORPHOSING, SHATTERING, AND MINERALIZING THEM.

On 1,100-foot level, McCormick crosscut, Silver King mine. Looking southeast.

STRUCTURAL FEATURES ILLUSTRATING GEOLOGIC HISTORY.

with the great Cretaceous deformation occurred an intrusion of dioritic magma. About the same time, or possibly shortly afterward, intrusions from a common dioritic magma produced the present bodies of diorite porphyry. These invasions of magma metamorphosed the sediments and induced the deposition of metallic sulphides (Pl. XXIII, *B*). Subsequently, after partial cooling of the intrusive masses, fracturing in a northeast-southwest direction recurred and opened passages from the magma for solutions which deposited additional sulphides. Movement was renewed later along these northeast-southwest fissures (fig. 6) and subsequently fracturing took place in a northwest-southeast direction. Some of the secondary fracturing may have occurred during the Jurassic elevation. After these events, probably in Tertiary time, a succession of extensive flows of andesite poured out into the depression between the Wasatch and Uinta ranges, blanketing the old surface. Some of the earliest flows invaded water bodies, burying waterworn pebbles. The presence of coal seams in the flows suggests either engulfment of considerable masses of vegetable matter from the inclosing shores of this molten lake, or the lapse of sufficient time between flows to allow considerable vegetation to grow. Since the cessation of these flows elevation appears to have gone on in the Wasatch Range which has tilted the eastern slope and its blanket of andesite toward the east.

The master drainage, interrupted by the volcanic eruptions described above and further retarded by the elevation of the Wasatch athwart its course, has become reestablished along new lines. Local glaciers which formed along the main divide and made their way out from the cirques at the heads of the principal canyons extended well out toward the foothills. They rounded out canyon walls, floored the valley bottoms with waste, and left low moraines along their margins. Surface waters descending along fracture zones have oxidized the sulphide deposits in their superficial portions. Surface streams have deeply incised their courses in the late lavas and much later glacial deposits and are to-day sinking their way into the bedrock, showing that the growth of the Wasatch is still in progress.

ORE DEPOSITS.

MINERALOGY OF THE ORES.

SPECIES AND ORDER OF DESCRIPTION.

The ores of this district are made up of the usual lead, copper, and zinc minerals and accessories. They contain neither rare species nor a wide variety of types. Alteration of lead sulphide affords a remarkably complete series of secondary products. Some of the tetrahedrite, somewhat unlike the normal in appearance, proves to be a zinciferous variety of that complex mineral. One or two occurrences of the capillary form of jamesonite were discovered. In association with massive and semicrystalline vesuvianite in marble adjacent to an intrusive contact, masses of spinel show crystals of exceptionally large size. Most notable, perhaps, are large masses of galena of the coarse cleavable variety intergrown with massive tetrahedrite.

The descriptions of the minerals in the following pages are arranged according to chemical composition, after Dana's "System of mineralogy," sixth edition, 1909. This arrangement may not prove so convenient in some respects as a grouping of all minerals of each kind of ore together, as such an arrangement necessitates certain arbitrary divisions, but it seems best for general purposes to follow the only constant order—that based on chemical composition. It is assumed that readers are familiar with general mineralogy, accordingly common mineralogic and crystallographic descriptions will be omitted except where there is something particularly worthy of note.

NATIVE ELEMENTS.

Gold.—The "gold ledge" in the Silver King mine, 700-foot level, is reported to have yielded considerable gold, but microscopic examination of the rusty material from that lode at most favorable points failed to reveal gold. Nevertheless, men who sluiced and washed tailings in Woodside Gulch below the Silver King and old Mayflower mills and also in Silver Creek in Park City proper are reported to have saved gold enough to make good pay. This was said

to be mainly in the form of flour gold, and a little was in fairly large grains. None was observed by the writer.

Silver.—It is stated by the operators that native silver was found in 1904 in the Scottish Chief mine. The point at which it was said to occur was in the main bed on the third level about midway between the main incline and the east incline. On careful search at the time of visit and examination of the best material, however, none could be recognized.

Copper.—Copper in its native form has been reported from several places. On examination of the material, however, it could not be detected. One of the closest resemblances, found in the Ontario drain tunnel near No. 2 shaft, proved to be merely a tarnish on pyrite. No occurrence of native copper was observed in this district.

SULPHIDES.

Galena.—The isometric lead sulphide (PbS) is the principal ore mineral in this district. It commonly occurs in massive form, both cleavable and granular, rarely crystalline, in fissures and beds in limestone and locally in quartzite. It is so widespread and is found under conditions so varied that a complete description of its geologic occurrence is impracticable. Hence the typical character, occurrence, and association of the more important varieties only will be briefly described.

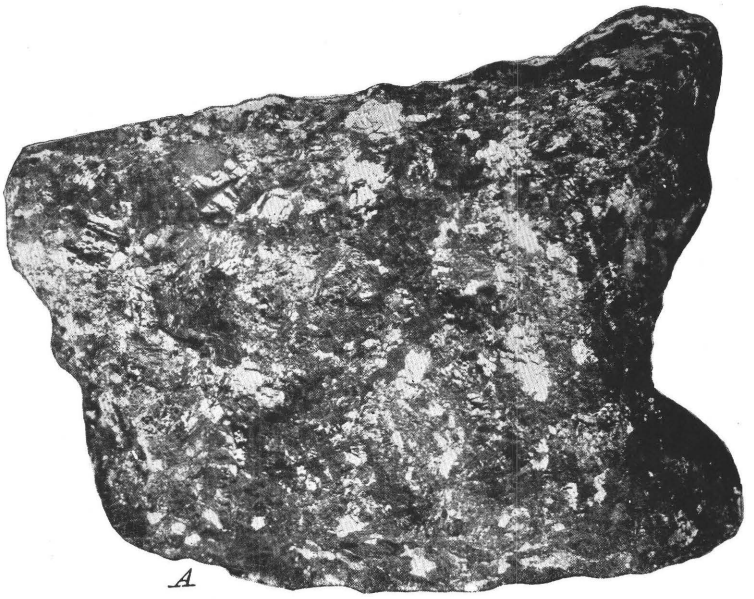
Three well-marked types may be noted—the coarse and the fine cleavable or granular and the crystalline. The coarse cleavable variety (Pl. XXIV) occurs in solid masses which in places show the characteristic cubical cleavage faces 2 inches across. From that maximum the size of the component cleavage pieces grades down through medium faces half an inch across to faces one-fourth to one-eighth inch across. Below this degree of fineness the grains are one-sixteenth of an inch or less and constitute the granular variety. The medium is perhaps the most common. Crystals are rare, though a few are encountered here and there. Thus a specimen of banded milling ore from the Ontario 1,500-foot level shows at its core, embedded in quartz, crystals about three-sixteenths of an inch across bounded by the octahedron modified by the cube. A closely similar occurrence, found on a slope above the 1,200-foot level of the Daly-Judge mine, shows larger but less perfect crystals. A specimen from the Daly West ore bins shows an aggregate of galena crystals somewhat coated and obscured, in which individuals apparently of octahedral form reach one-half to three-fourths of an inch in length.

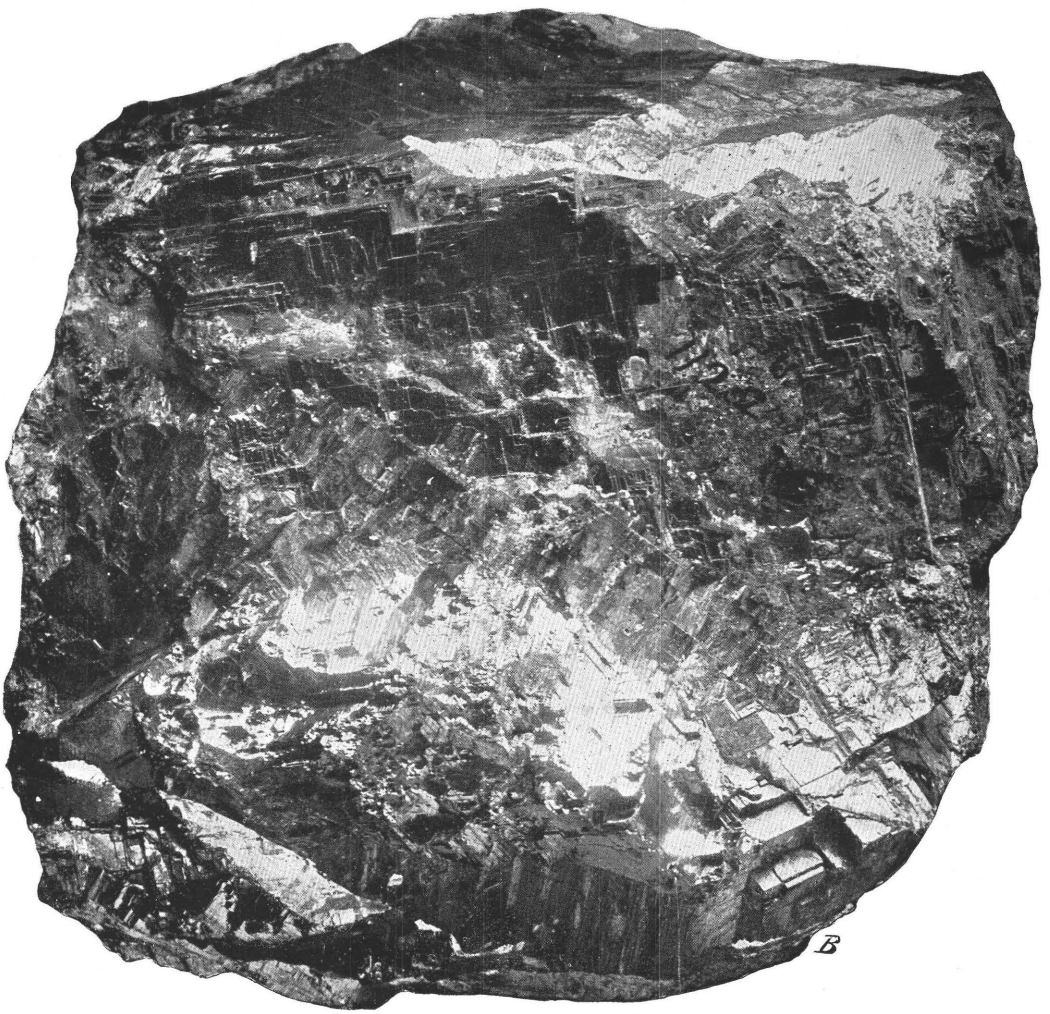
No constant relations could be determined aside from the fact that the crystalline form appears to be restricted to fissures. The massive cleavable and granular forms are found both in beds and in fissures.

It is the bedded ores that form the bonanzas of the district. Excellent examples of galena occupying beds were found in the Daly West stope A, also in the Big West stope of this mine on the 900-foot level, in the Quincy, in the Silver King 1,000 and 1,200 foot levels west, and on a smaller scale in the Kearns-Keith, Comstock, and Scottish Chief. The ore bed in the Daly West stope A was made up to a thickness of 5 or 6 feet by a succession of layers from 6 to 18 inches thick, including one of 8 to 10 inches of coarse galena, two fine-grained layers, and one of medium grain. A good bed of massive cleavable galena was cut in the King on the 1,000-foot level west.

The galena in fissures is indistinguishable in physical characters from that in beds. Excellent samples of medium-grained ore in a fissure were seen on the Daly West 1,400-foot level. A most remarkable and extensive body of coarsely-cleaved galena was opened in the "gash" vein in the Silver King at a depth of 1,150 to 1,200 feet. (See Pls. XLIII, p. 184; XLIV, p. 186.)

Rarely is the galena isolated. In stope A of the Daly West and the main stope of the Hanauer tunnel the bands of galena are roughly interbedded with similar bands of sphalerite and in one place with tetrahedrite. Fine-grained pyrite is locally scattered through the galena, as in specimens from the Daly West fissure 1,400-foot level and stope A. The coarse cleavable galena from the "gash" vein in the Silver King mine and also in the '02 fissure of the Daly





A. MEDIUM-COARSE CLEAVABLE GALENA, WITH SOME INTERGROWN PYRITE, SPHALERITE, AND TETRAHEDRITE.

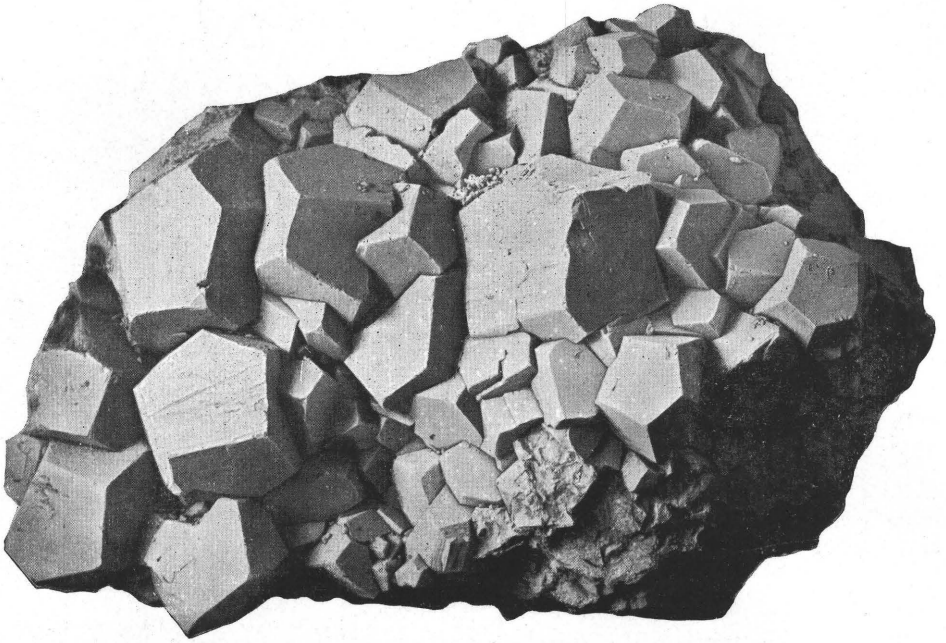
B. COARSE CLEAVABLE GALENA IN SOLID UNALTERED CORE, FROM FRAGMENT DRAGGED IN BRECCIA.

From 1,250-foot level, Silver King mine.

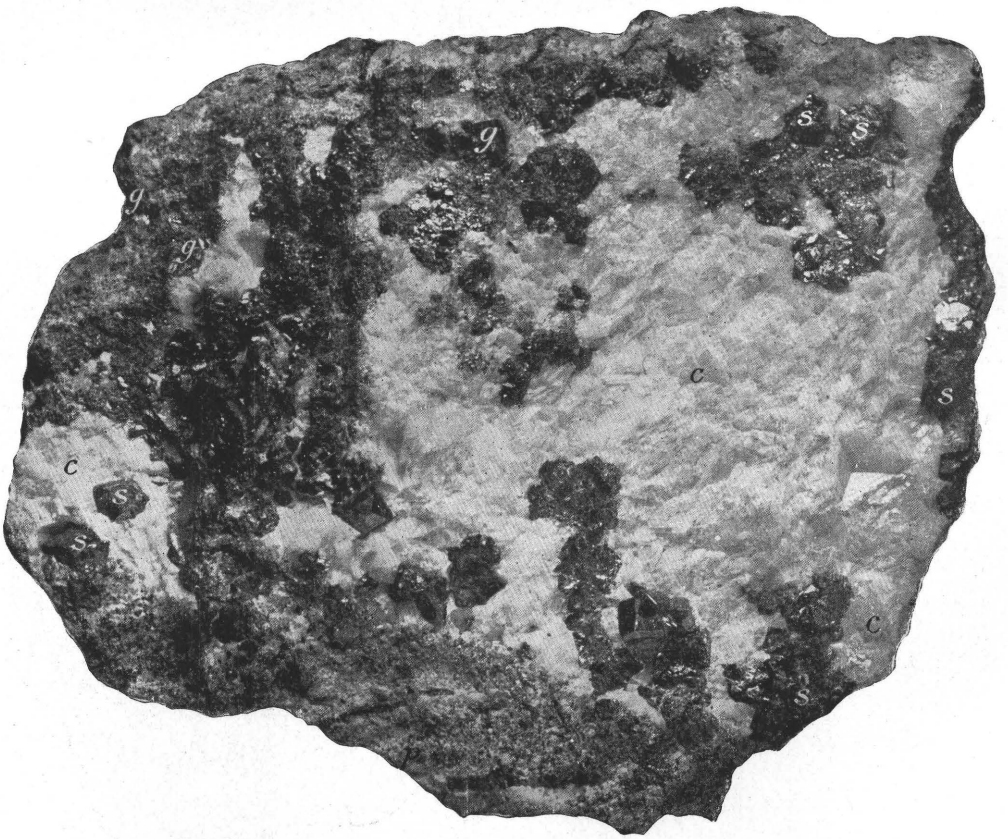
RICH SULPHIDE LEAD ORE.

RICH SULPHIDE LEAD-COPPER ORE, SHOWING INITIAL STAGES OF ALTERATION.

The mass is composed chiefly of coarse cleavable galena intergrown with massive tetrahedrite. Anglesite, cerusite, azurite, and malachite occur along seams and lining vugs. Gash vein, 1,050-foot level, Silver King mine. One-half natural size.



A. CRYSTALLINE PYRITE.



B. GRAINS OF GALENA (*g*) AND PYRITE (*p*) EMBEDDED IN INTERGROWN CALCITE (*c*), SPHALERITE (*s*), AND QUARTZ.

GANGUE MINERALS, DALY-JUDGE MINE.

West was intergrown with irregular masses of equal size (1 to 4 inches across) of tetrahedrite (Pl. XXV). Some silica and calcite are also present.

This very coarse type of ore, consisting of galena and gray copper intergrown, appears to be more characteristic of the strong fissures, and the granular galena and sphalerite in a very fine mixture or interbanded were encountered more frequently in replacement ore.

The alteration of these galena ores is exceptionally well shown in this district. Galena goes over to anglesite. This and the succeeding forms are described under the respective headings.

Pyrite.—The only iron sulphide observed in the district, pyrite, is a relatively unimportant constituent of the ores. It is probably most common in ores which occur in or adjacent to fissures. Its usual occurrence is in granular massive and semicrystalline form intergrown with other sulphides in lode ores or interbanded with them in lode and replacement ores.

In the Daly-Judge mine, on the 1,250-foot level west, coarsely crystalline and massive pyrite is embedded in massive sphalerite in a shoot in a lode. On the Comstock 250-foot level west massive pyrite is intergrown with massive galena in lode ore. In the great lodes of the Ontario and Daly West mines, on the lower levels, fine granular pyrite occurs in bands in silica and in irregular patches in areas of massive galena. In the latter occurrences the pyrite appears to increase in depth. Along some of the stronger fissures on the lower levels of the Daly-Judge mine areas of excellent crystals showing pentagonal dodecahedrons (Pl. XXVI, *A*) line open spaces, and some of these are crusted over with a thin film of blackjack. On the Ontario 1,500-foot level, near shaft 2, in a lode in limestone which is characterized by rhodonite, pyrite occurs in small grains in quartz and intergrown with sphalerite.

At several places pyrite occurs in bedded deposits. Thus in the Kearns-Keith mine, just below the Hanauer tunnel level, well-bedded zincky lead ore in limestone of the Thaynes formation adjacent to the main fissure carries pyrite interbedded in bands and intermingled with chalcopyrite. Similarly on the 700-foot level of the Silver King mine fine granular pyrite occurs in bands interbedded with galena, which together make a bed in the footwall limestone of the Park City formation. In specimens on the California dump, as in the wall of the main fracture underground, pyrite occurs replacing limestone beds alternately with sphalerite, also coating walls of joints.

Another mode of occurrence is seen on the spur at the head of Thaynes Canyon and next west of the Jupiter tunnel. In a horse of metamorphosed limestone in diorite, irregular pieces of pyrite are intergrown with garnet and magnetite. Again, in the hanging wall of the Crescent vein pyrite occurs disseminated through the porphyry mass, as under similar conditions it does in metamorphic limestone.

The pyrite in the above-noted occurrences is associated with sphalerite, galena, chalcopyrite, magnetite, quartz, rhodonite, rhodochrosite, garnet, and calcite, but most commonly with the first two. It has been found by precise tests to carry silver and is saved in some of the mills as an iron middling.

Chalcopyrite.—This sulphide of copper and iron is rarely encountered in the Park City district. In the few occurrences observed it is in massive form intimately intergrown with pyrite, galena, or sphalerite. On the 250-foot level of the Comstock mine west bands three-fourths of an inch wide and irregular masses of chalcopyrite with quartz gangue make up a 3-inch vein which lies immediately under the master diorite porphyry dike of the mine. A specimen from the California dump shows shattered massive chalcopyrite and pyrite in a siliceous breccia. Contact-metamorphic limestone forming a horse in diorite at the head of Thaynes Canyon shows grains of chalcopyrite and pyrite in garnet and magnetite.

Bornite.—Several specimens of mineral suggestive of bornite were found, but on chemical determination they proved to be other minerals. A coating of bornite on a specimen from the California dump was only a thin veneer on chalcopyrite. A specimen of rich copper ore from the ore bed on the third level in the Scottish Chief has a core of purplish mineral. Qualitative wet and dry tests, however, showed that it was not bornite but an unusual facies of tetrahedrite.

Chalcocite.—This black sulphide of copper, the most important of ore minerals in many camps, is rarely observed in this district. It occurs sparingly as a coating on chalcopyrite and on cupriferous pyrite, more commonly in fracture zones at moderate depth. Nowhere is it known to attain the form of a vein or solid minable mass.

Sphalerite.—The sulphide of zinc occurs abundantly in various forms throughout the district. The usual variety is of a rather deep brown to resin color and is found in massive specular form intergrown with ore minerals and in semicrystalline form. It is more common in lodes, particularly at considerable depth, and in beds in the Thaynes formation adjacent to fissures. It appears to increase with nearness to extensive intrusive bodies. Thus the great fracture zone in the Ontario, Daly West, and Daly Judge and the bedded ores adjoining fissures in the Kearns-Keith and California have revealed the greater part and best of the specimens.

The best-developed crystals, which singularly are from the Silver King mine, where the mineral is rarely found, occur embedded in quartz crystals. They measure three-fourths of an inch across and show the simple form of octahedron twinned on the octahedral plane. (See Pl. XXVII, *A*.) Similar though smaller and less completely developed crystals crusted with sheaves of calcite crystals were found on the 2,000-foot level of the Ontario mine, in the porphyry hanging wall of the Ontario fissure. A group of large, imperfectly crystallized masses of sphalerite partly overlaid with quartz crystals was taken from the Big stope on the 1,250-foot level of the Daly Judge mine. (See Pl. XXVII, *C*.) Irregular masses dispersed through the milling ores in the deeper parts of the great lodes are common.

A unique mode of occurrence was observed in the Big stope from the Hanauer tunnel, where bedded ore adjacent to a fissure is made up of thin layers of silica coated above and below with semicrystalline sphalerite. (See Pl. XXXV, *C*, p. 124.)

In other portions of this general ore-bearing bed sphalerite occurs in fine cleavable form intergrown with a relatively less amount of galena and small grains of chalcopyrite. In the Daly West bedded ore in stope A a little sphalerite occurs in a narrow band with galena.

The usual associates of this zinc sulphide seem to be galena, pyrite, quartz, calcite, and a little chalcopyrite. It is noteworthy that galena ores in which tetrahedrite occurs plentifully are low or lacking in sphalerite; reciprocally, those containing much sphalerite seem to be free or nearly free from tetrahedrite.

SULPHARSENITES AND SULPHANTIMONITES.

Tetrahedrite.—The mineral called gray copper is a complex sulphantimonite of copper ($4Cu_2S.Sb_2S_3$), which may contain arsenic and zinc. It crystallizes in the isometric system with tetrahedral habit. It occurs widely in this district in both lodes and bedded ores, somewhat more commonly in the former, in both massive and crystalline form.

In the Silver King mine, in the "gash" vein west, large irregular masses of typical gray copper 1 to 3 inches across are intergrown with similar masses of coarse cleavable galena through extensive bodies. (See Pl. XXV, p. 106.) This affords an excellent high-grade lead-silver-copper ore and is the source of the copper produced by this mine. This tetrahedrite appears to be primary. A similar occurrence was noted in the Daly West mine, in the general '02 fracture zone, where a body of somewhat altered coarse massive tetrahedrite intergrown with galena occurs in limestone immediately over diorite porphyry. Ore of this class in each of these mines affords exceptionally perfect examples of alteration of its constituent minerals, the tetrahedrite going over to malachite and azurite, the arsenic and antimony uniting with products from galena to form a complex oxidized product.

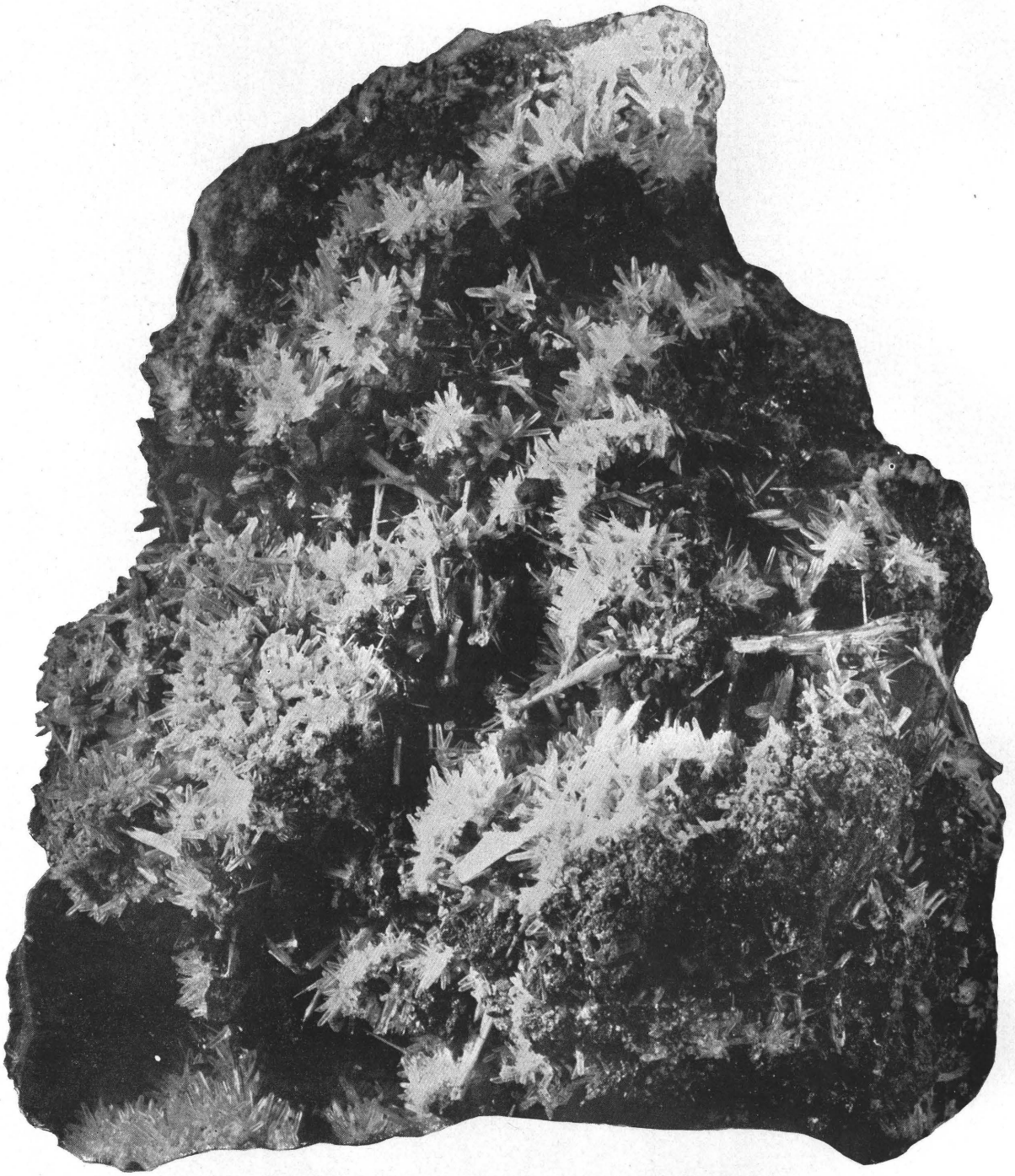
A somewhat rare type of this mineral was found in the Daly-Judge mine, on the 1,400-foot level west, in a single pear-shaped mass on an obscure fracture or pipe. Intergrown with brown sphalerite are irregular masses of a mineral resembling the typical gray copper. It has the brassy hue of that mineral but seems rather more vitreous and its general appearance suggests a zinciferous tetrahedrite. An analysis by George Steiger, of the Geological Survey, revealed the following composition:

A. TWINNED SPHALERITE CRYSTALS (OCTAHEDRA TWINNED ON OCTAHEDRAL PLANE) EMBEDDED IN QUARTZ CRYSTALS, SILVER KING MINE.

B. CRYSTAL OF TETRAHEDRITE CRUSTED WITH SPHALERITE AND PERCHED UPON AGGREGATE OF QUARTZ CRYSTALS.

C. CRYSTALLINE SPHALERITE (*s*) AND PYRITE (*p*) INTERGROWN WITH AGGREGATE OF QUARTZ CRYSTALS (*q*).

CRYSTALLINE MINERALS.



CRYSTALS OF TETRAHEDRITE, CERUSITE, AND QUARTZ INTERGROWN UPON WALL OF CAVITY IN LIMESTONE, SILVER KING MINE.

Analysis of tetrahedrite from Daly-Judge mine.

Antimony	21.30
Arsenic	5.54
Copper	37.87
Silver	1.49
Iron	.95
Zinc	7.59
Manganese	.02
Sulphur	25.66
	100.41

This analysis, when compared with the analyses of typical tetrahedrite and tennantite, indicates that this mineral is tetrahedrite high in arsenic and zinc.

Massive tetrahedrite also occurs in bedded ores, as in the Daly West, in stope A, and in the Big West stope, on the 900-foot level. In the former it is in grains scattered among galena and in narrow bands and in the latter it occurs in bands in beds of zincky lead ore.

A specimen from the Roll fault zone, 900-foot level, Daly West mine, shows a vug in a specular galena-tetrahedrite ore, lined by half an inch of massive and crystalline tetrahedrite covered in turn on the inside by aggregates of quartz crystals. The tetrahedrite crystals are usually simple unmodified tetrahedra about three-sixteenths of an inch across (Pl. XXVII, *A*), though one larger one was found (Pl. XXVIII).

The most common associate of this mineral is galena, less frequent is sphalerite, and some pyrite and chalcopyrite and quartz are also found with it.

Jamesonite.—Three specimens of a crystalline gray metallic mineral were found on the California dump. Dense drab metamorphic limestone is traversed by veins of quartz one-eighth inch to 1½ inches thick showing rough amethystine structure with in-facing crystals. The irregular sinuous open space along the center is marked by a narrow dark-gray line which in places where the open seam expands to small cavities is tufted with small bunches of capillary crystals. These have a dark steel-gray color and a brilliant metallic luster. Some of the quartz crystals on which these tufts rest contain many delicate gray hairlike crystals which closely resemble these in the cavities. The material was too meager to permit thorough chemical determinations, but Dr. Hillebrand obtained qualitative tests for sulphur, antimony, and a salt of lead, and accordingly is inclined to regard the mineral as jamesonite or warrenite. Associated with it at one point were small crystals of brown sphalerite. It may be noted that gray metallic crystals that were found by the writer at Cananea in similar geologic occurrence and association were chemically determined to be jamesonite.

CHLORIDES AND FLUORIDES.

Cerargyrite.—A specimen of rich copper ore from the ore bed in the Scottish Chief mine at the third level was reported to carry high values in silver. On chemical examination Dr. Hillebrand detected a chloride which he is inclined to regard as that of silver—cerargyrite. It was not found, however, in sufficient quantity to recognize with the naked eye.

Fluorite.—This mineral was found in intimate association with lead-silver ore in two mines and was suspected at a few other points. In the Woodside mine at the foot of the Carey incline, near King ground, fluorite occurs in lenses and bunches in bedded lead ore and in adjoining limestone. The pale-green and purple varieties occur in massive layers, which, like the inclosing ore, are much shattered. In one place aggregates of partly formed crystals an inch across were found apparently showing the octahedron, possibly modified by the cube. In this occurrence the fluorite seems to be contemporaneous with the ore. In the Silver King mine, in the Clover Leaf stope, 60 feet above the 900-foot level north, fluorite was found in altered bedded ore. Other possible occurrences were not positively determined.

OXIDES.

Massicot.—One of the principal features of the mineralogy of the ores in this district is the earthy yellowish material resulting from the alteration of lead minerals. It varies from a dusty, bright-yellow coating through dull waxy, rusty and brownish yellow or flesh-colored solid masses inclosing cores made up of concentric layers of cerusite, anglesite, and galena. In the mixed galena-tetrahedrite ore the products of oxidation of copper are also present. Qualitative analysis of the material shows that it is a mixture of several secondary lead minerals. Most careful attempts to isolate any particular class of this material for analysis were only partly successful, as the analysis indicates the presence of several minerals, probably including the lead monoxide (PbO), massicot; the complex hydrous antimonate of lead, bindheimite; a little of the arsenate of lead, mimetite; probably other lead compounds; limonite; and calcite.

The bright-yellow powder, especially that associated with the isolated galena free from gray copper, is doubtless the normal lead oxide, massicot, containing 92.8 per cent of lead. This occurs associated with altered lead ore in patches upon altered galena, in some places boring the mass itself along fractures. Singularly the most advanced and complete stages of this oxidation were found at considerable depth, on the 1,200-foot level west in the Silver King mine. It is in a general zone of fracture, but in places the ore, which has been very completely oxidized, appeared to lie along bedding.

Massicot is associated with the above-named products of decomposition of lead, apparently of contemporaneous date, also with the carbonates of lead and copper, the sulphate of lead, and the primary minerals galena and tetrahedrite.

Cuprite.—No specimen of cuprite which can be determined positively as such has been found. A specimen of limonite specked with malachite, from the dump of the Jupiter lower tunnel, shows fine glistening brownish-red grains which suggest cuprite. Again, a specimen of rich copper ore from the Scottish Chief mine contains a mineral of reddish hue which resembled cuprite, but wet tests yielded antimony, proving that this mineral is not cuprite, and further examination showed it to be tetrahedrite.

Magnetite.—This mineral has been found in a number of places in the district, but is not common. It occurs with garnet as a contact mineral developed in limestone adjacent to intrusive rocks.

Specularite.—The micaceous or specular variety of hematite occurs as a contact-metamorphic mineral in limestone adjacent to intrusive rocks at several points. It is most abundant in the contact zone at the southern head of Thaynes Canyon and along the overlooking divide to the southwest. The Thaynes formation was here invaded by diorite magma, which apparently extended northward underneath the sediments and is exposed by erosion of the amphitheater that holds Shadow Lake. Along the zone immediately overlying this intrusive and adjoining the dikes that break upward across the bedding the limestone is highly metamorphosed. The specularite occurs in sheaves, in curved folia, in large irregular masses, and in bands closely associated and intergrown with the products of contact metamorphism of the limestone. Green garnet is most abundant, with much calcite, some greenish quartz, and probably some epidote.

Limonite.—This hydrous oxide of iron is found most abundantly in the oxidized superficial parts of ore bodies which have an iron base. Workings in ore zones near the surface have in several places revealed extensive masses of limonite. The shallower portion of the Ontario lode on the 300-foot level is an instance. In the Valeo mine, however, the development of limonite is, so far as observed, more extensive than elsewhere in the district. The ore zone is oxidized and heavily limonitic on all levels. The lower tunnel opened a northeast fracture dipping southeast, roughly parallel with and steeper than the bedding, which yielded a large mass of limonite for use in smelting. The ocherous powdery variety was carefully traced back to successively less oxidized stages until it was clearly observed that the massive oxide was derived from pyrite.

Pyrolusite.—A black mineral occurs commonly in the form of a dense black coating and also as a sooty powder on croppings of ore shoots and underground ore zones. An excellent sample taken from the cropping of the Ontario lode was determined by Dr. Hillebrand to be an "oxide of manganese." Some of this is doubtless manganese dioxide (MnO_2), pyrolusite, and some may be the hydrous oxide ($Mn_2O_3.H_2O$), manganite. It appears to lie in the zone of oxidation and to prefer fractures, being frequently present in siliceous breccias. It is popularly regarded as a good sign of ore.

Quartz.—Quartz is found in many forms throughout the district, both massive and crystalline, but is not particularly abundant. It occurs so widely and so variously that only the more significant forms can be described here. In both lodes and beds the massive variety is a common gangue of the ore. In beds it is locally porous and honeycombed, as on some of the upper levels of the Silver King mine and on the Hanauer tunnel level. In lodes a massive gray silica commonly forms the body of the vein, with sugary quartz occupying areas among the metallic constituents. In the ore-bearing fracture zones in Daly-Judge ground on the west geodes formed, in which some excellent quartz crystals were found. One such specimen, which is the property of the Park City Bank, showed single crystals 3 inches across and 5 to 6 inches long. Another from the same locality shows sphalerite crystals embedded in and partly coated by aggregates of small quartz crystals. One of the most perfect crystals seen was found in the dump of the Jupiter lower tunnel. It is 1 by $2\frac{1}{2}$ inches and shows at least four rhombohedra. Beds in the ore bed of the Kearns-Keith mine, Hanauer tunnel level, have been altered to bands of quartz one-fourth inch thick parallel with the bedding, with upper and lower surfaces formed of quartz crystals.

The more common associates with the quartz are sphalerite and galena.

Spinel.—In the southwest corner of the area, 2,550 feet S. 35° E. from Clayton Peak, a bowlder about 2 feet in diameter was found in talus about at the contact of the main diorite mass with limestone. The limestone along the contact is highly metamorphosed, showing contact minerals, and this bowlder is a solid mass entirely made up of two contact minerals—spinel and vesuvianite. (See Pl. XX, *A*, p. 100.) The spinel, normally a magnesium aluminate, is in the form of a blackish-green massive to semicrystalline material in irregular masses intimately intergrown with vesuvianite and some mica. The green masses are honeycombed with vugs which contain aggregates of octahedra, including some individuals one-fourth of an inch across.

CARBONATES.

Cerusite.—The carbonate of lead occurs commonly throughout the district as a normal product. Its more usual occurrence is in crevices or pits in galena which are lined with a thin zone of anglesite that bears inside a velvet-like layer of minute tabular pinkish to pearly-white crystals of cerusite. This was most perfectly displayed in the large masses of galena-tetrahedrite ore from the "gash" lode in the Silver King mine at depths of 1,000 and 1,100 feet. (See Pl. XXV, p. 106.) Similar occurrences, though in a more advanced stage, are encountered in upper workings, locally in the form of dull-white coatings. Another form of the mineral that is much more beautiful was found in the Silver King mine at the west end of the Mammoth stope between the 900 and 1,000 foot levels, where the master fracture zone traverses the Park City formation. An open space in the ore body which formed in this zone bears upon its infacing walls aggregates of cerusite crystals, of quartz crystals, and of an indeterminable crystal, possibly of tetrahedrite. The cerusite, which appears to have been the last of these late minerals, is in the form of slender conical or minute acicular crystals (Pl. XXVIII, p. 109). Some are 2 inches in length and are pearly white; others have a steel-gray coating (Pl. XXII, *A*, p. 102). These crystals seem to differ from the type described above in that they are incrusted directly upon galena. Apparently in the more common form the cerusite was derived from the anglesite and indirectly from the galena upon which it rests, but in the occurrence just described it was transported from an outside source and deposited upon this fresh unaltered galena. Another unusual and possibly misleading occurrence was discovered in the Scottish Chief mine, on the

third level, at the head of the east incline. A specimen of rich lead ore composed largely of anglesite shows vugs lined with a glistening mineral of pale robin's egg blue color, which proved on chemical examination by Dr. Hillebrand to be cerusite stained with copper.

Malachite.—The comparatively rare occurrence of the primary copper sulphides results naturally in a corresponding dearth of the alteration products. They are, however, encountered here and there in the zone of superficial alteration and along fractures affording waterways. Some are found in the Silver King mine on walls of stopes on the great bedded bodies between the 800 and 900 foot levels, also just below along fractures. In stopes at the 1,200-foot level of the same mine the carbonates of copper and lead occur covering fragments of quartzite and filling cracks in that rock. Malachite there forms a coating of small botryoidal masses made up of minute crystals and with a dark-green velvet-like surface. On the sulphide ores of this mine in the "gash" vein, also in the fracture zones ('02) in the Daly West, malachite occurs as a coating on gray copper, and in the former locality it forms velvet-like tufts and patches on the walls of vugs. The usual associates are azurite and cerusite.

Azurite.—The blue carbonate of copper, although somewhat less rare than the green, is not often found. Its localities include those where malachite is found. The walls of the replacement body in the stope in the Silver King between the 800 and 900 foot levels showed a solid bed of a massive azurite one-fourth to one-half inch thick. The specimen from the fracture zone just below shows slender bundles of acicular crystals similar to those of the associated cerusite, except that these are of azurite color throughout. It is uncertain whether the copper carbonate merely stains or entirely replaces the lead carbonate. The tetrahedrite ores show a coating of azurite, apparently the latest deposition. On Crescent Ridge old open-cut workings on croppings of fissure ores in limestone revealed pockets of small azurite crystals.

Rhodochrosite.—Two possible occurrences of rhodochrosite are known. A portion of a gangue mineral determined chemically to be rhodonite gave a slight intumescence, which was probably due to the presence of some of the carbonate, rhodochrosite. Again a specimen of pink semicrystalline material showing aggregates of minute curved rhombohedra is either rhodochrosite or colored dolomite.

Calcite.—A relatively unimportant part is played by calcite among the minerals of the district. It occurs locally as gangue in zinciferous lead ores, usually in bedded deposits but here and there in lodes. (See Pl. XXVI, p. 107.) In the porphyry hanging wall of the Ontario vein at the 2,000-foot level it occurs in sheaf-like aggregates of crystals on zinc crystals as the latest deposit. Similarly it forms a recently deposited gangue for zinciferous galena in the Daly-Judge lode at the 1,200-foot level.

Dolomite.—Dolomite has not been recognized as of common occurrence, though in several places it is believed to be present associated with calcite. A mineral from a fissure underlying porphyry, on the 1,700-foot level of the Ontario mine, shows light-pink crystalline material with vugs containing aggregates of curved rhombohedra. These may be rhodochrosite or dolomite colored by manganese.

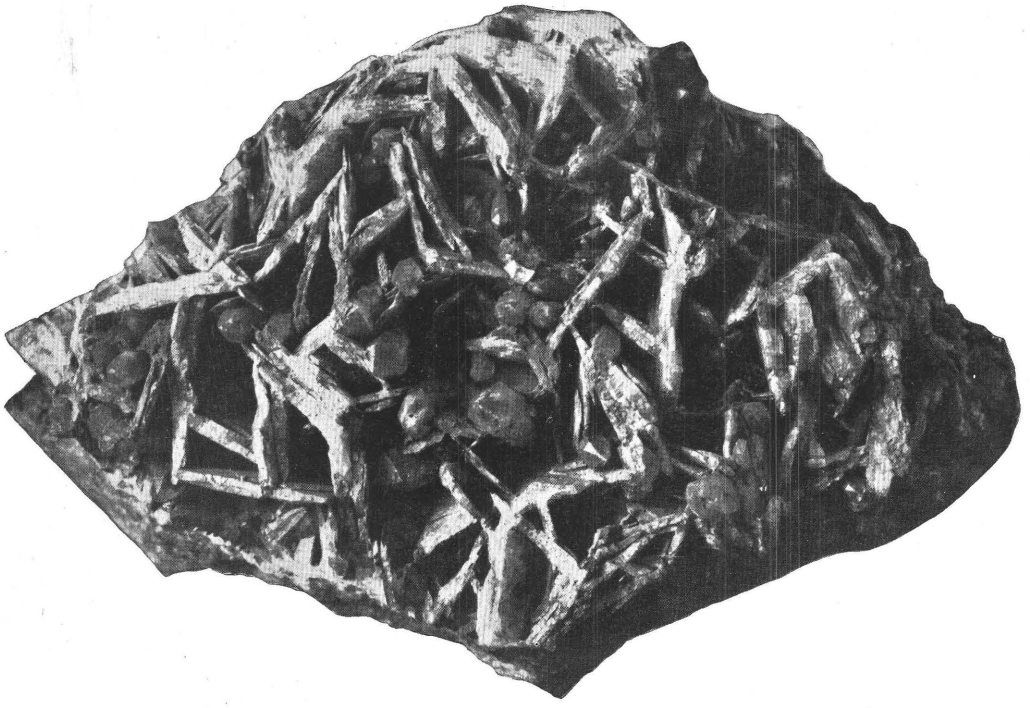
SILICATES.

Chrysocolla.—The hydrous silicate of copper, chrysocolla, is occasionally found. The best example seen occurred with tetrahedrite in the main ore bed of the Scottish Chief mine, on the third level east.

Garnet.—In certain localities garnet is somewhat abundant, notably in the southern part of the district in limestone adjacent to the great diorite intrusive of Clayton Peak. It is most commonly in dark-green massive form and apparently replaces beds of limestone for a considerable extent, though occasionally brown and partly crystalline garnets are found. Thus, around the head of Thaynes Canyon extensive development of massive green garnet appears where limestone lies adjacent to diorite on Bonanza Flat. The upper outcrops of limestone near the diorite show extensive metamorphism and contain contact minerals, including dodecahedral crystals of cinnamon-brown and of light-green garnet in calcite. The croppings of the ore shoot of the Scottish Chief mine contain small crystals of green garnet in calcitized limestone. Garnet was also found sparingly underground. On the 600-foot level of the Wabash

A. GRAINS OF TETRAHEDRITE, PYRITE, AND SPHALERITE IN GANGUE OF QUARTZ AND RHODONITE.

From vein in metamorphic limestone, 1,500-foot level, Ontario mine.



B. BARITE AND QUARTZ CRYSTALS INCRUSTING QUARTZITE.

Wall of fissure, Flagstaff mine.

GANGUE MINERALS OF LODE ORES.

mine, northwest, dark-brown garnet occurs in metamorphic limestone with chlorite and calcite immediately over an intrusion of diorite porphyry. Again, at the dump of the Parleys Park shaft, massive dark and light brown and green garnet is found, apparently from the deeper workings. In brief, garnet occurs in this district in limestone adjacent to intrusive rocks and associated with calcite, epidote, wollastonite, chlorite, specularite, and pyrite.

Vesuvianite.—Vesuvianite, a tetragonal basic calcium-aluminum silicate of uncertain formula, was found in the southwestern part of the district along the southern contact of the intrusive of Clayton Peak with limestone, where it composed the greater part of a large bowlder apparently nearly in place and intergrown with spinel (Pl. XX, *A*, p. 100). It is massive and semicrystalline, is light olive to medium brown in color, has vitreous luster, and shows large partly formed striated crystals. Some incomplete, apparently tetragonal crystals of a grayish olive-brown mineral physically resembling vesuvianite were found on the north contact of this intrusive. The associates of vesuvianite observed are spinel, garnet, and calcite.

Epidote.—This mineral occurs in massive form associated with garnet and specularite in metamorphic limestone adjacent to the Clayton Peak mass of diorite. It is not common.

Chlorite.—Chlorite occurs in altered limestone adjacent to intrusives at several points on the surface and underground. In the Clayton Peak mass of diorite and contiguous to it are found aggregates of small greenish hexagonal crystals which Lindgren is inclined to regard as quartz colored by innumerable minute included crystals of chlorite.

Serpentine.—This mineral is formed in seams and beds in decomposed fractured metamorphic limestone on the 1,500-foot level near No. 2 shaft of the Ontario mine. Some approaches the precious variety and some shows a tendency toward the fibrous variety, chrysotile. It is not common.

Rhodonite.—The silicate of manganese, rhodonite, is rarely found in this district. The best occurrence noted was on the Ontario 1,500-foot level near No. 2 shaft, where it appeared as a gangue mineral associated with quartz in a lode carrying galena, pyrite, and sphalerite (Pl. XXIX, *A*).

Mica.—In association with silicates which formed in contact zones adjacent to intrusive rocks, pale bluish green imperfect crystals of mica are found. These probably belong to the chlorite group, though some may be muscovite. One or two specimens of blackish hexagonal crystals of mica were seen. All of these appear to lie at or near an igneous contact.

Chabazite.—In the contact zone along the southern margin of the Clayton Peak stock small pearly-white crystals fleck the metamorphic material. The best specimens of these were found by Dr. Schaller to be rhombohedra of chabazite. They are apparently the last of the minerals formed and are associated with vesuvianite and garnet.

PHOSPHATES.

Pyromorphite.—In certain croppings and upper portions of shoots of lead ore pyromorphite is probably present in small quantities, but it has not been found in sufficient amount nor definiteness to determine.

Phosphate rock.—Among the rocks collected in 1902, during the preliminary study of this portion of the Wasatch Range, were specimens from a bed in the Park City formation which was observed at several points on the surface and also underground. Later private persons made a study of this formation in Utah, Nevada, Wyoming, and Idaho, and as a result the mining of phosphate rock from certain of these beds was undertaken. Systematic geologic work on the subject was then taken up by the United States Geological Survey and much valuable information on the character and extent of these beds has been gained.[1]

The specimens of the rock collected in the Park City area were given to Mr. Gale for use in his detailed study of this subject. In brief, it appears that the bed is rich in phosphate and is

[1] Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: Bull. U. S. Geol. Survey No. 430, 1910, pp. 457-535. Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Idem, pp. 536-553. See also Bull. 470, 1911, pp. 371-481.

lithologically and stratigraphically equivalent to the main phosphate beds which are worked commercially elsewhere. The rock from this bed is suggestive of fossils, yet does not seem to afford identifiable remains. It has a dark brownish gray color and high specific gravity, being about three times as heavy as ordinary rock. On close examination it is seen to be composed of small irregular fine-textured black grains and minute white and pale-bluish specks.

On the surface it was found at the head of Empire Canyon in the rock cut immediately in the rear of the Little Bell shaft house. Underground it was recognized in the Silver King mine at the 300-foot level. Gale states that a specimen from the Silver King yielded on analysis 32.60 per cent of P_2O_5, which is equivalent to 71 per cent of bone phosphate and shows a phosphate rock of good grade. The bed, which was approximately 3 feet thick, was noted at several points. Its position in the Park City formation at the Little Bell is about 300 feet above the Weber quartzite, and at the Silver King it is probably the same.

In the report of Gale and Richards it is concluded that the CO_2 yielded by this rock may be present in a phosphatic mineral of the nature of podolite ($3Ca_3(PO_4)_2.CaCO_3$), and that the phosphate mineral "closely approximates in composition a basic calcium phosphate, probably more basic than apatite because of the presence of the haloids, to which further investigation may warrant the assignment of a new name."

ARSENATES.

Mimetite.—This mineral is a combination of lead arsenate (90.7 per cent) and lead chloride in hexagonal crystals (9.3 per cent). It is believed to be present in the yellow oxidation products from the galena-tetrahedrite ores. Qualitative chemical tests led Dr. Hillebrand to consider the material to be "essentially an antimonate of lead and iron. * * * A part of the antimony is replaced by arsenic, but possibly the latter comes from mimetite, since there is some chlorine present." It would thus appear that a part, probably a small part, of the oxidized material is mimetite.

ANTIMONATES.

Bindheimite.—Dana defines bindheimite as "a hydrous antimonate of lead, but analyses vary widely and no general formula can be given." [1] It is noncrystalline.

In the Park City district the oxidation of galena-tetrahedrite ores yields an amorphous greenish or olive-yellow material, which is resinous, soft, and in places powdery (Pl. XXII, *B*, *C*, p. 102). Crushing and screening seem to show that it is composed of different substances, the greenish being the coarser portion and the clear canary-yellow composing the fine powdery product. To the naked eye this material shows some plain light-yellow and some olive-yellow particles, some malachite, also grains of galena and of a vitreous colorless material. Under the microscope these differences appear to be about the same, the yellowish material possibly being differentiated into two kinds. A quantitative analysis of selected cleaned material shows that the elements present do not belong to any single known mineral, hence the material is doubtless a mixture of several minerals. The iron oxide, calcium oxide and carbon monoxide, and silica present are probably in the form of limonite, calcite, and quartz, respectively. The water is not a constituent of any mineral, as it passed off at blast, 100° and 180°. The copper may be in grains of pure malachite or in a stain through the yellow material. There remain lead, antimony, and arsenic as probably the essential constituents of the principal mineral, with a very little zinc, copper, and silver possibly as impurities. These essentials recalculated would stand in about the relation that they do in the mineral bindheimite, if arsenic may be held to have replaced a portion of the antimony. It seems most probable, then, that the bulk of this yellowish oxidation product is bindheimite.

SULPHATES.

Anglesite.—The sulphate of lead occurs widely in moderate quantities in the lower part of the zone of oxidation, in both lode and replacement bodies, as the first product of the alteration of galena. It is commonly massive, dull gray, and of waxy luster. Rimming cavities in massive galena, it forms a zone one-eighth to one-fourth inch wide between the galena, its source, and

[1] Dana, E. S., System of mineralogy, 6th ed., p. 862.

cerusite, its product. Here and there considerable masses have formed upon the surface of galena, but usually it is found in comparatively thin bands, evidently owing to its ready transition to the carbonate. A dull dark green color is probably caused by a little copper from tetrahedrite. Excellent examples of this mineral are found in the Silver King mine, in the heavy sulphide ores which show the earliest stage of alteration. (See Pl. XXV, p. 106.)

Chalcanthite.—The common hydrous sulphate of copper is rarely met in the mines of this district. Occasionally some is found in wet ground below ore deposits, particularly in lodes, as in the Ontario mine on the 1,600-foot level east, and near shaft 2 on the 1,700-foot level west.

Barite.—Barite was found at a prospect on top of Flagstaff Mountain, where it had apparently incrusted the walls of fissures in quartzite. It occurs in aggregates of intergrown plates locally arranged in radiate form. (See Pl. XXIX, *B*, p. 112.)

Gypsum.—Gypsum was found in massive form on the dump of an old working of the Summit Co. at the head of Thaynes Canyon, where it apparently has been formed by mine waters. In a specimen of ore from the Wabash mine, 600-foot level south, presented to Mr. Lindgren, he noted gypsum of semicrystalline to fibrous varieties forming the gangue of a granular zinciferous galena-tetrahedrite ore.

Goslarite.—This hydrous sulphate of zinc was seen in small amounts in old workings on walls in the form of fibrous tufts.

COAL.

A seam of soft coal and some carbonized wood were found interbedded with the andesite flows which overlie the sediments in the northeastern part of the district. The Ontario drain tunnel starts in andesitic flows and passes west-southwest (S. 76° W.) through this formation for nearly 5,000 feet. At a point 2,350 feet in from the mouth a seam of coal occurs in fine-grained andesite. It strikes N. 20° to 30° E. and dips 36° NW. The seam is from 2 to 18 inches thick and is exposed on the wall of the tunnel for a distance of 45 feet. The outer portions are composed of fine-grained carbonized wood which includes at its core a 2-inch seam of normal coal. The seam thus has no commercial value beyond affording some basis for search for a more extensive body. The occurrence is interesting, however, consisting of perhaps the latest coal known in the West, very late Tertiary; also as showing the effect of the overflowing andesite in devolatilizing the organic material.

OCCURRENCE OF THE ORES.

TYPES OF ORE.

The ores of the Park City district occur as lode deposits and as bedded deposits in sedimentary and intrusive country rocks. The two types of deposits are commonly associated throughout the region, though some lodes and veins occur alone. The principal lodes extend through the heart of the area in a northeast-southwest direction across Ontario, Empire, and Woodside canyons. The chief bedded deposits have been found in Empire and Woodside canyons. Deposits of both types also occur on the east and west. The fissures trending northeastward carry the lode ores in the intrusives as well as in quartzite and limestone. Bedded ores are most extensive and of highest grade in the Park City formation, and occur to a minor extent and are poorer in quality in the Thaynes formation. Valuable deposits of bedded ore have been mined to a depth of somewhat more than 900 feet, and rich lode ore has been found to depths of 1,200, 1,400, and 1,500 feet, and good milling ore at 1,700 and 2,000 feet. In general, the deposits appear to be closely associated with either fissures or intrusive rocks.

LODE DEPOSITS.

CROPPINGS.

Several fissures that bear ore outcrop in this region. The best instance is probably the Ontario lode, in Ontario Canyon (Pl. XXXII, *A*, p. 120). One of the locators of this great mineralized fracture zone has stated that the cropping of this lode consisted of "a little knob sticking out of the ground about 2 inches high," and that this was "the only cropping of the lode which was ever found." At the time of the writer's examination that part of the vein had been

opened and showed on the surface as a zone of crushed quartzite 2 feet wide between definite parallel fissure walls. This zone had been traced along the surface for about 1,100 feet, also downward for 2,000 feet. In general, the same structure appears throughout—a strong fracture zone traversing massive quartzite. At the point of discovery and along the strike the filling was crushed mineralized quartzite that had undergone secondary and possibly tertiary silicification. The quartz formed is dull, honeycombed, chalcedonic, milky, and massive. The mineralization is indicated by black, brown, green, and yellow stains. The black and brown are manganese oxide, the green is crystalline and amorphous malachite, and the yellowish stains, which are termed by the prospector "chlorides," are not so readily determined but are probably due to alteration products of galena, such as pyromorphite, the oxide, massicot, and the arsenical antimonate, bindheimite. This discoloration or deposit is a common feature on siliceous croppings. On the strike toward the west at a point just west of the Daly boarding house is a rusty quartzite ledge, which is usually regarded as the cropping of the extension of this lode, and south of that, in the fork of the road, is another ledge of quartzite showing sheeting, which is held to be the apex of the vein at that point. Neither of these outcrops shows any mineralization beyond silicification and some staining with iron.

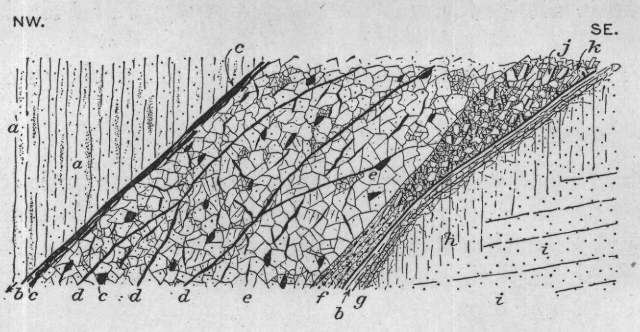


FIGURE 7.—Section showing character, structure, and contents of Ontario lode—pay streaks and bunches of ore in brecciated quartzite with siliceous gangue. *a*, Sheeted quartzite with iron stains; *b*, slip plane; *c*, ore; *d*, slip planes; *e*, white brecciated quartzite, mineralized in spots; *f*, 8-inch banded brecciated quartzite; *g*, 6-inch crushed quartzite with black manganese bands; *h*, sheeted quartzite; *i*, massive quartzite; *j*, massive quartz; *k*, crushed quartzite with stains of copper and iron.

Several other veins and lodes, for example, the New York lode, show rusting along a fracture zone. Some of the fissures on Crescent Ridge are similarly mineralized and show also copper carbonates.

CHARACTER.

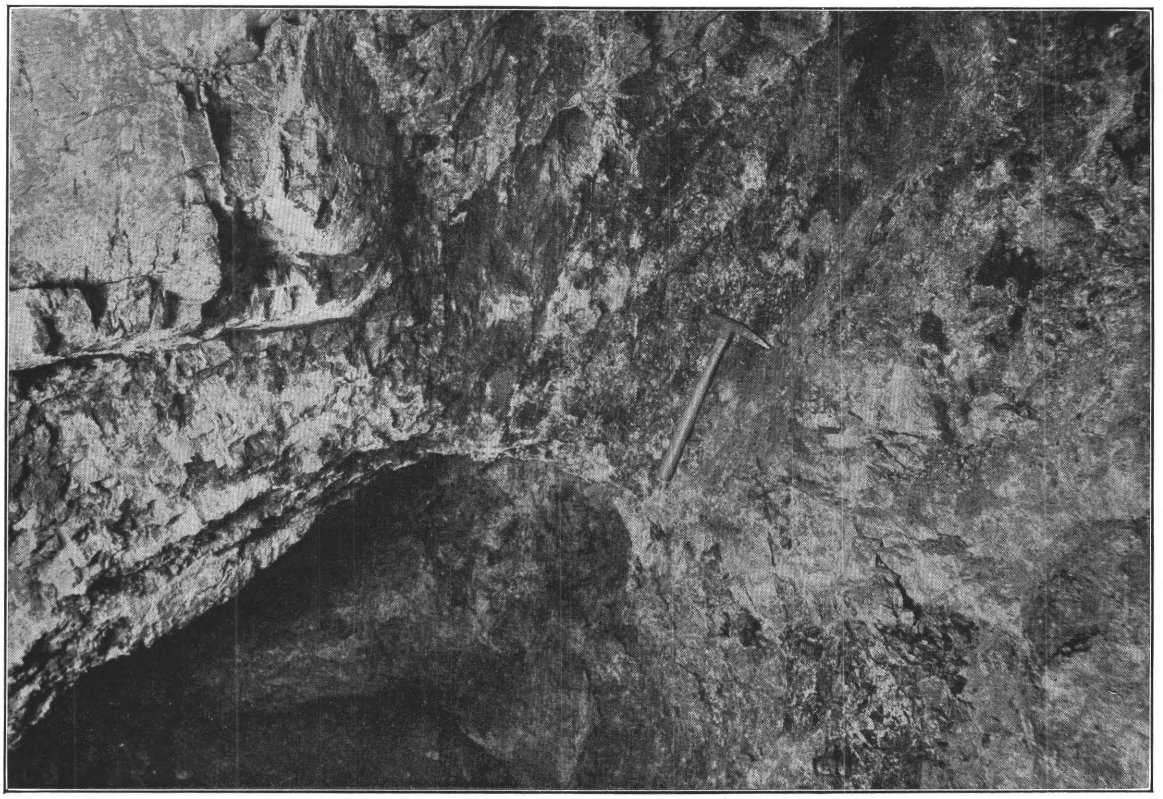
The lode deposits of this district are extensive, strong, and valuable. They lie in a few continuous master zones, rather than in a large number of small fissures.

These deposits may be characterized as argentiferous lead ores with some zinc and, in certain places, copper. The lead is afforded in the upper portions by the carbonates and oxides and below by the sulphide and some sulphate. The silver appears to lie in the pyrite and galena. Zinc is present as the sulphide. Copper appears as carbonates in the upper levels and to some extent at the intermediate levels, but occurs mainly in the deeper levels in tetrahedrite.

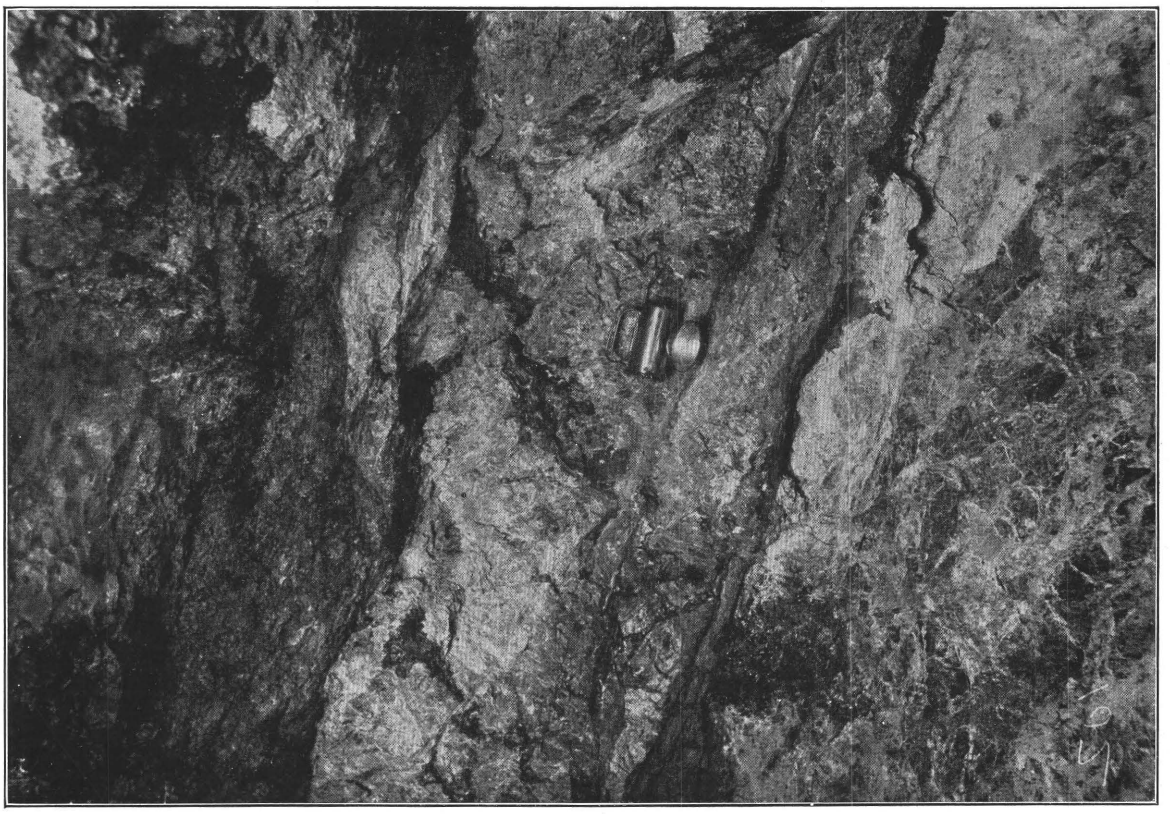
In general the upper parts of these deposits have proved richest, the middle section has been of high grade, and the deeper portions larger but leaner. This is well shown in the Ontario lode. Exceptions are known, however; thus, in the Silver King mine in several places the grade of the ore in the "gash" vein increased with the depth.

Some continuous seams or solid bands of ore occur between frozen contacts. The greater part of the lodes being worked at the present day, however, consist of disconnected seams and bunches of rich sulphide ore scattered through much waste in the fracture zones (Pl. XXX). Thus, in some of the small properties and on the upper (300 and 600 foot) levels of the Ontario mine, especially in the footwall of the master lode, the ore lies in thin seams frozen to the walls. In the Silver King mine at the lower levels broad bands or tabular masses of solid sulphide ore were found entirely filling fissures. The other, more common, form of deposit is admirably exhibited in the Ontario mine on the 1,500-foot level, and the Daly West mine on the 1,400 and 1,500 foot levels. A strong fracture and breccia zone 100 feet in width is occupied by crushed quartzite which includes seams, streaks, and bunches of sulphide ore (fig. 7).

Intermediate types of occurrence are shown in the Daly West stopes between the 1,400 and 1,500 foot levels. These consist of single streaks in a wide zone of breccia at or near either wall and a number of pay streaks distributed roughly parallel through the zone. Perhaps the best example of this type of lode deposit was seen at the extreme west end of the Daly West



A. GENERAL ZONE OF FRACTURING WITHOUT DISTINCT WALLS.
"Gold ledge," 10 feet above 900-foot level west, Silver King mine. Looking southwest.



B. BARREN ZONE OF STRONG FRACTURING IN QUARTZITE.
Main Ontario zone, 1,500-foot level, Ontario mine. Looking northeast.

FRACTURE ZONES.

1,500-foot level. Here, as indicated in the sketch (fig. 8), a lode 35 feet wide is made up of two strong ore streaks on the foot and hanging walls and many narrow seams and lenses of ore occurring on fractures within the lode.

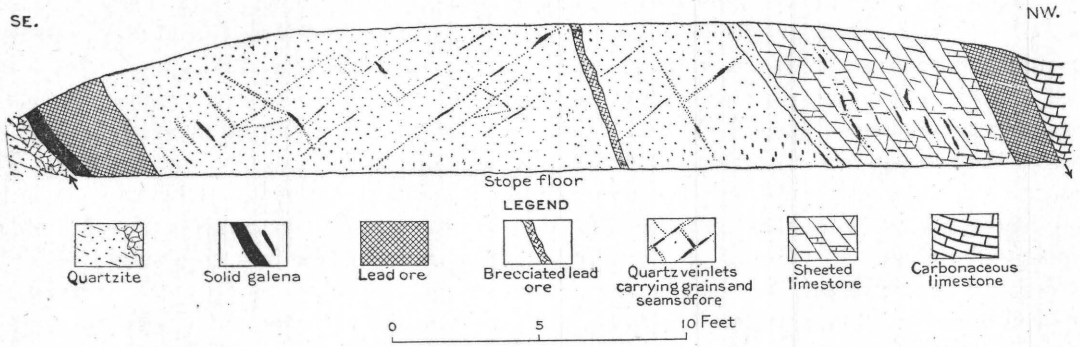


FIGURE 8.—Transverse section of ore shoot in lode, stope above 1,400-foot level west, Daly West mine. Hanging wall carbonaceous limestone; footwall quartzite; pay streaks, on footwall, 6-inch solid galena overlain by rich lead ore; on hanging wall, zinciferous lead ore in limestone. Intervening country rock is sheeted and fractured and is traversed by quartz veinlets carrying grains, seams, and bunches of ore.

AREAL DISTRIBUTION.

The lode deposits lie in a general east-west zone about 3 miles wide which extends across the central part of the area from the west nearly to its eastern boundary. On the north and south some fracturing is found but no noteworthy mineralization except in this particular zone. Beyond to the south another zone crosses Snake Creek and some of the fissures which cut the north side of that canyon have been found to carry good ore. Within the main Park City zone the master lodes, comprising the great Ontario-Daly West system and the Silver King group, traverse the ground exposed by Ontario, Empire, and Woodside gulches for a distance of about 3 miles along their strike and through a width of 2 miles. To the east, in the course of the zone, ore-bearing fissures and lodes have been found in McHenry, Wasatch, Glencoe, and Cottonwood canyons, and to the west of the master lodes, in the same course, other lodes extend across upper Thaynes Canyon. Those on either end, however, are relatively small.

Within this main area of master lodes (see Pl. XXXIX, p. 132) two subzones are seen. The Ontario-Daly West system lies at the southeast side and includes most of the important lodes. The Silver King subzone lies about a mile to the northwest. Between these two subzones some fissures are found and a few lodes, for example, the American Flag. In general, however, the great lodes lie in two northeast-southwest zones about a mile apart.

FISSURE SYSTEMS.

The grouping of fissures into systems according to their trends, which has proved most significant in certain districts, does not appear to be practicable in the present area. With comparatively few exceptions the fractures follow general east-west courses. Here and there transverse fissures trending in a general north-south direction are found. Intersections are extremely rare. Characteristic members of the prevailing system are seen in the Ontario and Daly West fissure zones and the Silver King and Kearns-Keith fissure zones. The principal members of the other system recognized on the surface are a fissure that is followed by the eastern margin of Deer and Frog valleys, known as the Frog Valley fault, and one that extends from the Daly-Judge tunnel northwest across the Massachusetts shaft toward the Silver King shaft, known as the Massachusetts fault.

Intersections along these strongest members of the lesser system could not be made out. The fairly accordant alignment of the known portions of the Frog Valley fault and topographic features athwart the course of the east-west faults marked by Drain Tunnel Gulch and McHenry Canyon suggests that the north-south system is the younger. The Massachusetts fault was not observed on the surface or underground in juxtaposition with any other fault.

Underground, in the Silver King, Kearns-Keith, and Daly West mines, members of the main east-west system are in a few places cut by small fissures of the north-south system. This

evidence accords with that noted on the surface in tending to show that the latter system is the younger.

Highly characteristic of the greater fissure system in this district is a branching or forking habit. Thus in both the southern series opened through the Ontario, Daly, Daly West, and Daly-Judge mines and the northern series opened through the Woodside, Mayflower, and Silver King mines the fissures of the east-west system appear to divide and subdivide. This feature is best shown in the Ontario mine, where a number of these branches or "spurs" have been extensively developed. (See Pl. XXXI, in pocket.) Critical examination of their junctions indicates that these spurs are true branches contemporaneous with the parent fissures. They usually diverge slightly and then continue roughly parallel to the original fissure. It is hazardous, however, to conclude unqualifiedly that these "spurs" are not portions of oblique fissures cut by the master fissure, as the physical appearance of the junctions might be similar with either manner of origin. But so far as known no continuations (truncated extensions) have been found in the hanging wall, hence it is most probable, as above stated, that the "spurs" are true branch fissures.

LODE SYSTEMS.

The system which trends east-northeast and west-southwest appears to include most of the great lodes. This fact is clearly seen on noting the trends of the principal productive lodes as follows: Ontario lode, N. 60° E. (average); Daly West lode, N. 60° E.; Silver King lodes, N. 60°–80° E. So far as the present study revealed, most of the other lodes are branches from lodes of this prevailing trend or closely approach this trend.

LOCALIZATION IN SHOOTS.

Unfortunately, large portions of the extensive workings on the veins are inaccessible. Nevertheless, certain fairly well-defined localizations of ore into shoots were recognizable. Thus, stope maps and sections published by the Ontario Co.[1] indicate an extensive strong shoot descending from the surface on either side of Ontario Canyon, pitching steeply westward to the

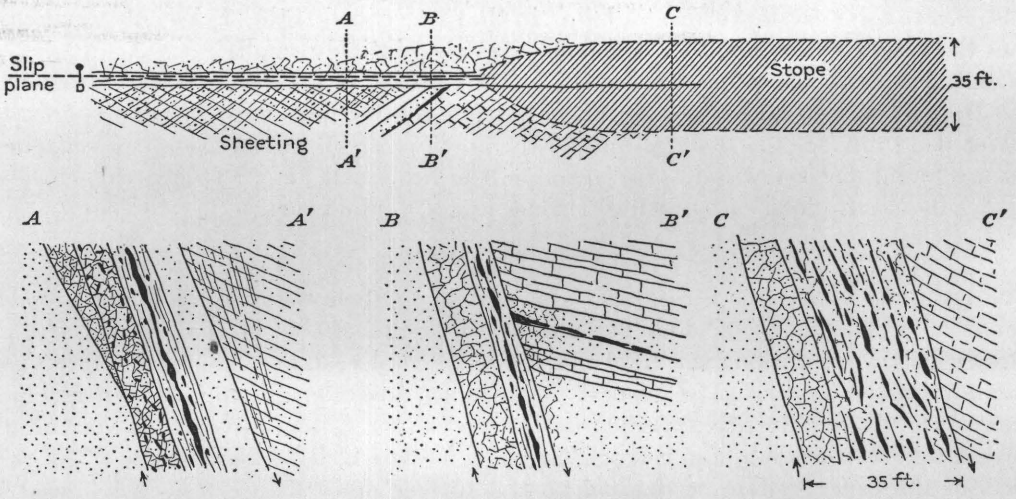


FIGURE 9.—Plan and cross sections of Daly West lode, stope over 1,500-foot level west. Shows expansion of ordinary vein of broken seams of galena, sphalerite, and tetrahedrite into shoot lying between quartzite footwall and interbedded limestone and quartzite hanging wall. Section *B–B'* shows thin lens of ore replacing bedding in hanging wall, apparently fed by original vein and truncated by postmineral fault.

lowest levels. Another of less extent, on the west, was opened through raise 3, and a third in the vicinity of raises 4 and 5. The section showing these stoped portions largest above and narrowing downward is quite probably misleading and indicates the form of the parts of the lode which afforded ore of a certain grade, beyond which weaker mineralization doubtless extended. It appeared underground that enlargement of the lode occurred at the junction of the master lode with a few "spur" or branch veins, but intersections or forkings could not be established as the determining cause of the greater shoots. It seems not improbable that their

[1] Ann. Rept., Jan. 1, 1899.

location and form may be governed by that of passageways and inequalities in the original fissure.

In the Daly West similar localizations of ore or enlargements of the lode were found comprising two major and several minor shoots. One at the west end of the property is about 600 feet in length and at a point just above the 1,400-foot level is 35 feet in width. Its detailed structure and the distribution of ores within it are indicated in figure 8 (p. 117). The second shoot, lying north of the shaft, had been opened on the 1,500-foot level for a length of 300 feet and a width of 30 feet. This shoot is unlike the former, which has bands or pay streaks of good width and tolerable persistence, in that the ores are distributed rather evenly in seams and bunches through a mass of crushed gangue (fig. 9).

The ore of the lodes in Silver King ground was not, so far as could be observed, localized into definite shoots. The nearest approach to one occurred in the "gash" lode near the Donkey winze. This was a lens or wedge-shaped mass of high-grade galena ore 20 feet through at its thickest part and followed 200 feet on its dip. It feathered out upward and laterally and terminated abruptly downward. No good reason for its location was apparent.

In several of the smaller mines—for example, the Scottish Chief and Valeo—small shoots have been opened. When any evidence for their formation could be found, it seemed to be either the form of the original fissure, or intersection with a feeding fissure, or shattering and consequent greater permeability of the country rock.

RELATION TO WALL ROCK.

The influence of wall rock upon lode ore, whether as regards position, amount, or character, was not observed to be very marked. At several properties certain relations were reported, but evidence of some of these relations could not be detected.

Long observation in the Ontario mine seems to have given rise to the saying that the highest-grade silver-lead ore lies between quartzite walls, whereas the porphyry on the lower levels of that property seemed to inclose more ferruginous and zincky material than other walls above. Limestone walls naturally lend themselves to replacement, and thus are apt to inclose the widest and most irregular lodes of the replacement type. For this reason, probably, veins were observed to expand between calcareous walls and to contract on reaching more siliceous or quartzitic walls.

The physical character of the wall rock seems to have influenced the character of fissures in a number of places. Thus, in the Ontario the massive quartzite seems to favor strong, even, well-defined fractures; limestone apparently breaks under stresses less readily and more unevenly, and porphyry causes the greatest irregularities and indefiniteness.

PERSISTENCE.

In general, the fractures in this area are strong, well defined, and notably persistent. The best example is found in the Ontario-Daly West system. The main Ontario fissure has been explored continuously along its strike for approximately 5,000 feet and the Daly-Daly West fissure, in the footwall of the Ontario and beyond to the west, for approximately 5,000 feet. Within these fissure zones the Ontario lode has been mined for a distance of about 4,000 feet, and thence along spur 2, the Daly and Daly West veins, a great lode has been mined for approximately 5,000 feet more. The character of the termination of the Ontario fissure on the east could not be observed, as it had been opened in the early days, and the workings were closed at the time of visit, but it was described as ending abruptly on a transverse fault. Its western extension showed, at the most western point opened, as a strong zone of sharp, well-defined fissures and brecciation with every indication of continuance. The ore within this fracture zone, however, pinched out nearly a thousand feet back to the east by normal feathering out, and the long stretch of comparatively barren fracture zone evidently discouraged further work. No good evidence is known, however, that another shoot may not be found beyond to the west. Similarly, the great Daly West lode where opened in Daly-Judge ground west of that shaft showed a strong fracture zone, and reports of latest developments indicate good ore contents.

The fracture zones containing the strongest lodes in Silver King ground, the "gash" and the "gold ledge," appear to continue with good strength beyond the extreme points opened. But the ore in them pinched out, and, owing to the barren unmineralized aspect of the fracture zones beyond, exploration was not carried further, though the possibility remains that the continuations of the zones may contain ore. Smaller lodes show similar features.

The persistence of fissures in depth has been well said to be approximately proportional to their extent along their strike—that is, the longer and stronger the fissure the greater the depth to which it may be expected to extend. The fissures and fracture zones of this district are no exceptions to this broad generalization. Thus, the long Ontario zone has been opened continuously from the surface to the 2,000-foot level. On the 1,700-foot level it is wider, stronger, and more sharply defined than at the surface. (See Pl. XXXII, *B*.) On the bottom, or 2,000-foot level, it lies largely in porphyry, where it is naturally less distinct, but even at this depth it shows great strength, excellent walls, and widths of 1 to 2 feet. The mineral contents vary considerably, being greatest and richest between the 500 and 800 foot levels, especially from the 600 to the 750 foot levels, and good below to the 1,500-foot level, where the width rose to 100 feet and the ore became a low-grade milling ore. Below this level between limestone walls, and particularly on the lowest level in porphyry, the ore was of low grade and carried much iron and zinc. This zincky ore on the bottom level occurred in two shoots—one east of the shaft and the other west.

To the west the Daly West lode at a depth of 1,500 feet at the time of visit appeared like the Ontario lode at the 1,500-foot level—a notably wide zone of low-grade or milling ore carrying considerable iron and zinc in a gangue of silica. It is reported that development at lower levels has since revealed the continuation downward of similar features.

The fractures of the "gash" lode in Silver King ground seemed to extend downward in the form of a broad zone of sheeting. The main shoot in this zone was reported by the operators to have terminated below sharply at a depth of 1,100 feet along a regular plane.

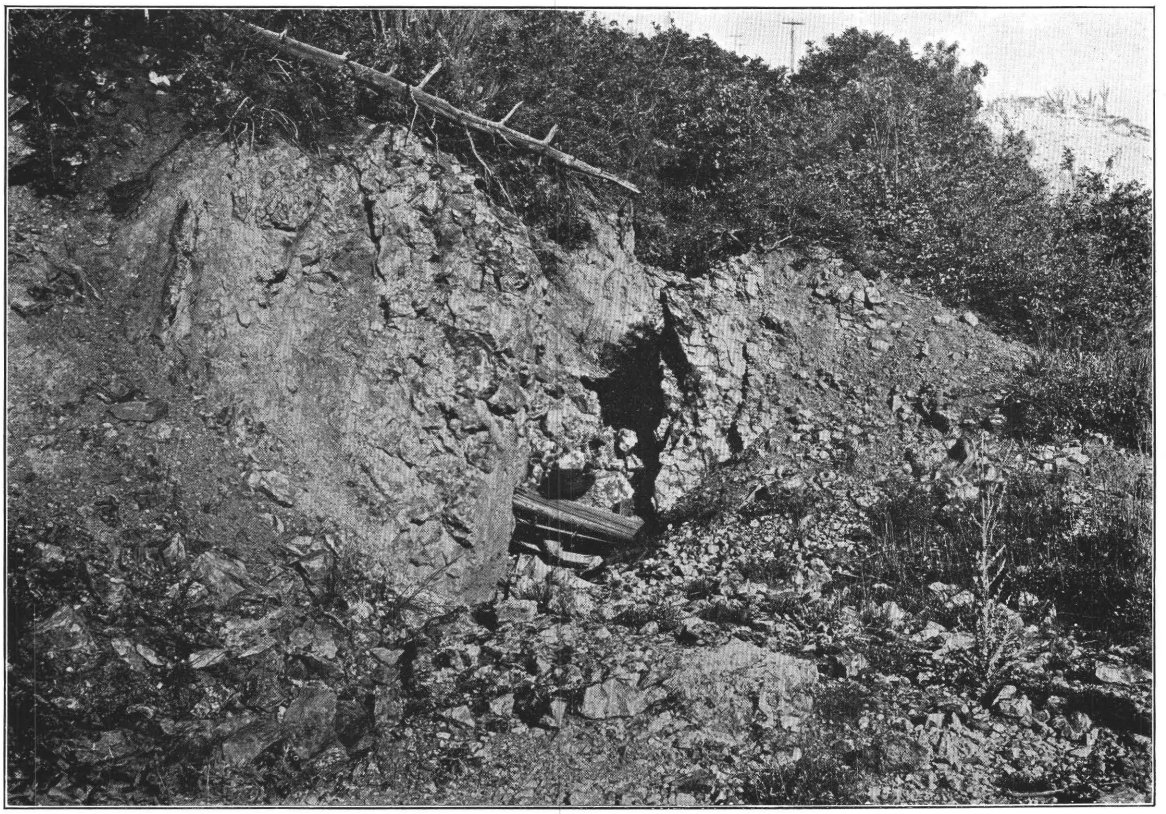
In some of the lesser mines shoots have been bottomed and in others found to persist to the deepest point worked.

In brief, it appears that although certain shoots of high-grade ore have given out at depths of approximately 1,000 to 1,500 feet, the fracture zones persist beyond the greatest depths explored with great strength, and some carry bunches of high-grade ore, but others only large masses of milling ore.

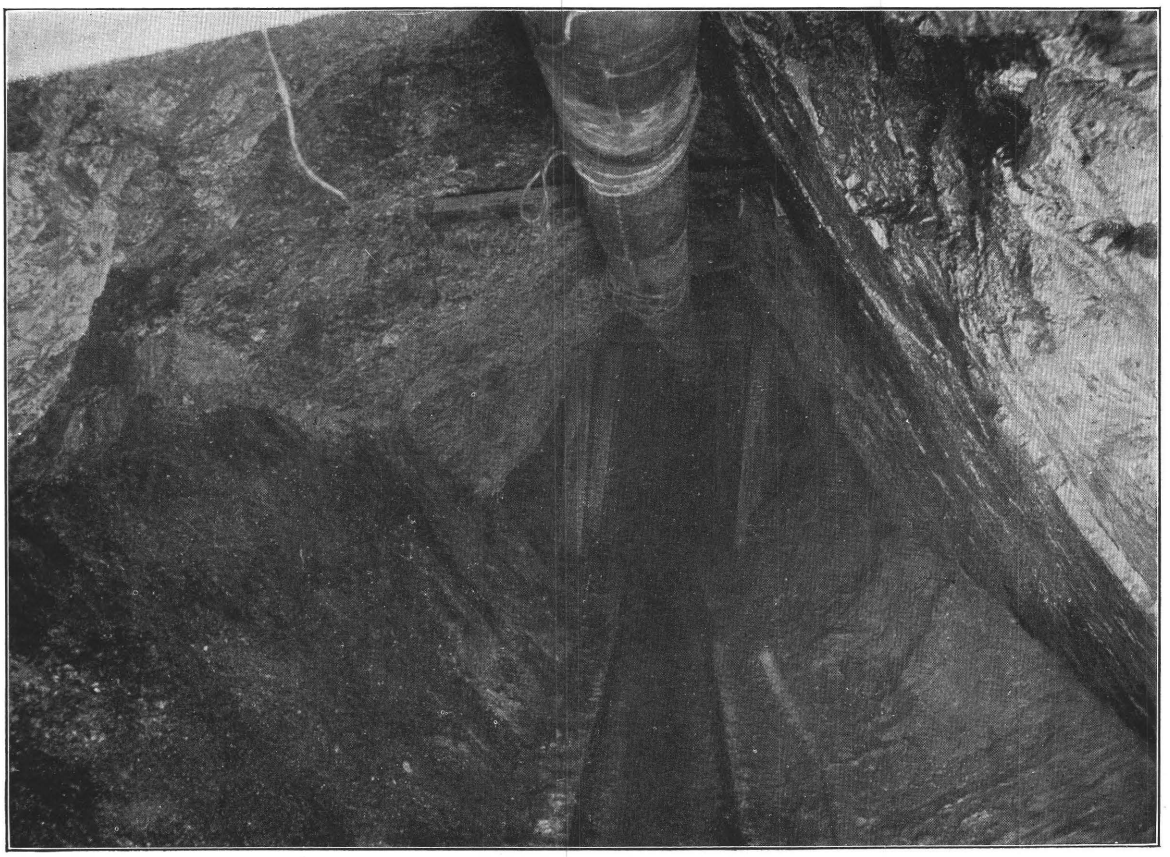
BEDDED DEPOSITS.

CROPPINGS.

Two great series of bedded deposits have been opened—that in Silver King ground and that in Daly West ground—and a number of minor deposits, including those in the Daly-Judge, Kearns-Keith, and Comstock mines. Certain outcrops have been held to be apexes of known ore bodies below, and underground work in connection with ownership litigation was asserted to have established continuous connection between ore bodies and croppings. It is unfortunate that the areas in which the beds that include the large, rich ore bodies would normally outcrop are deeply buried beneath glacial deposits. The known distinct cropping of the great Mayflower ore body led to an ore shoot which descended gradually into Silver King ground and might naturally be taken for a bedded deposit. Although its inclination was doubtless influenced by the limestone beds, the parts of the shoot observed by the writer tend to show that its position and course are closely connected with fissures and that it can not be regarded as a normal bedded deposit. Its cropping was stated to have been a mass of solid galena. North of the mouth of Walker & Webster Gulch, about 400 feet directly above the Daly-Judge mill, a fracture zone contours the slope and at certain points marks the surface contact between the Weber quartzite and the Park City formation. Parts of this zone, which has been mined out, are stated to have been mineralized. It is reported that in the noted Fairview suit this was claimed as the apex of certain Silver King ore bodies, and an attempt was made to demonstrate this by making a connection. At the time of the present survey the evidence on this point was inaccessible.



A. CROPPING OF ZONE AT "DISCOVERY," BETWEEN QUARTZITE WALLS.
Looking northeast.



B. ZONE ON 1,700-FOOT LEVEL, BETWEEN WELL-DEFINED WALLS OF LIMESTONE AND PORPHYRY.
Looking southwest.

ONTARIO FRACTURE ZONE.

The outcrop of the great ore-bearing bed in the Daly West ground and the croppings of shoots in this bed were not detected. The connection of the Daly West ore bed upward in the Quincy and Little Bell has been a mooted point, and its positive demonstration is rendered most difficult by complications due to intrusion and faulting. The cropping of the Quincy ore-bearing bed, the equivalent of the Daly West bed, is stated to have been found at the east end of the present mine and just below the present wagon road. A connection between this cropping and the 100-foot level is stated to have followed the main shoot from the surface to the great ore bodies underground, but examination failed to reveal ore either in the raise or in the croppings. About the headward slopes of the canyon the extensive intrusive mass of porphyry occupies the area in which the contact between Weber quartzite and Park City formation and the contact with the overlying ore-bearing member would normally outcrop. Again, a fault which traverses the bottom of the canyon just east of the Little Bell shaft may have dropped the ore-bearing member, so preventing its outcrop. The cropping of that member was not observed in mapping this region. Thus, in neither the Silver King nor the Daly West area were actual croppings of known bedded ore bodies observed.

On the southern slope of Scott Hill, however, on the Scottish Chief property, there are apparently true croppings of a bedded ore body. In a calcareous series galena, anglesite, and cerusite occur in a gangue of calcite, garnet, and limonite within a bed of coarse marble. This ore-bearing bed has been followed underground and a shoot developed which appears to be the downward extension from these croppings.

CHARACTER.

The bedded deposits form the bonanzas of this district. Many of them are large, continuous, and of high grade. Fortunately the bulk of these ore bodies lie comparatively shallow, so that the advantageous commercial conditions—high-grade ore in large, minable bodies relatively near the surface—here exist. The profits from these deposits have enabled the younger large properties, such as the Daly West and Quincy and Silver King, to assume quickly and securely their rank among great producing and dividend-paying mines.

In general these ores are sulphides, with some oxides of smelting grade. Those from the deeper or isolated parts of the beds are mainly galena, some gray copper, and pyrite. In certain places sphalerite is present in considerable quantity. The galena is both coarse and fine cleavable. In the oxidized portions anglesite, cerusite, an antimonate, probably bindheimite, and malachite are also found. Calcite and quartz form the prevailing gangue. The ores are commonly dense and heavy, only the highly oxidized portions being lighter in weight, semiporous, and powdery.

AREAL DISTRIBUTION.

If the general area mapped (Pl. II, p. 44) were divided into quarters by north-south and east-west axes and the resulting northwest quarter similarly quartered, the resulting southeast quarter would be found to embrace practically all the bedded deposits of importance in the Park City district. In other words, the valuable deposits of this class have been found on the upper north side of the main eastern spur from the Wasatch Range, which forms the main divide of the district. They thus lie about the headward portions of Empire, Woodside, and Thaynes canyons, where are the Daly West, Quincy, and Daly-Judge mines, the Silver King mine, and the Comstock and Scottish Chief mines, respectively. Excellent types of bedded ore are also found in Walker & Webster Gulch and are developed in the Kearns-Keith mine. Aside from these, only certain minor bedded deposits were observed.

GEOLOGIC DISTRIBUTION.

The bedded ores occur in sedimentary formations which adjoin the northern flank of the great Clayton Peak laccolith of diorite and dip north and west over Weber quartzite. Further, it is the calcareous sediments in which the ore bodies are found. The Park City and Thaynes formations contain the bonanza ore. The Weber quartzite is known to carry a few small and isolated beds, which do not aggregate sufficient ore to be of commercial importance. The two

red-shale formations, the Woodside and Ankareh, are not known to be ore bearing. In the two calcareous formations the siliceous members are commonly barren. In these two productive formations much the larger number of bodies and much the higher grade of ore has been found in the Park City formation, which contained the extensive bodies of rich bedded ore mined from Silver King and Daly West ground and some from the Daly-Judge. In the Thaynes formation, however, were found some of the bedded bodies in the Daly-Judge, Kearns-Keith, Comstock, California, and Scottish Chief mines.

The character of the ores from the two formations is most distinct. Those from the Thaynes formation are commonly high in sphalerite, iron, and silica. In general they are much lower in grade and much less desirable for either smelting or milling than the ores from the Park City formation. As compensation, however, they afford the zinc product which in recent years has been turned to excellent commercial advantage.

It appears further that not only is bedded ore practically restricted to these two formations, but even to certain members. This is more notably true of the ore in the Park City formation. The position of the ore-bearing members was studied with special care.

The most favorable opportunity to determine it was in the Daly West mine, on the 900-foot level, in the south crosscut at the west end of the property. This crosscut passes from the Park City formation southward, transverse to the strike of the bedding, through the ore-bearing beds and the lower portion of the formation, into the underlying Weber quartzite. It appears that the bedded deposits occur mostly in a certain limestone member which lies approximately 50 feet above the Weber quartzite. This member, which is here from 4 to 6 feet thick, lies between a hanging wall of fine siliceous gray impure limestone and a footwall of brown sandy quartzite. This favorable series is underlain successively by the following beds:

Section of beds below ore-bearing member in Daly West mine, 900-foot level.

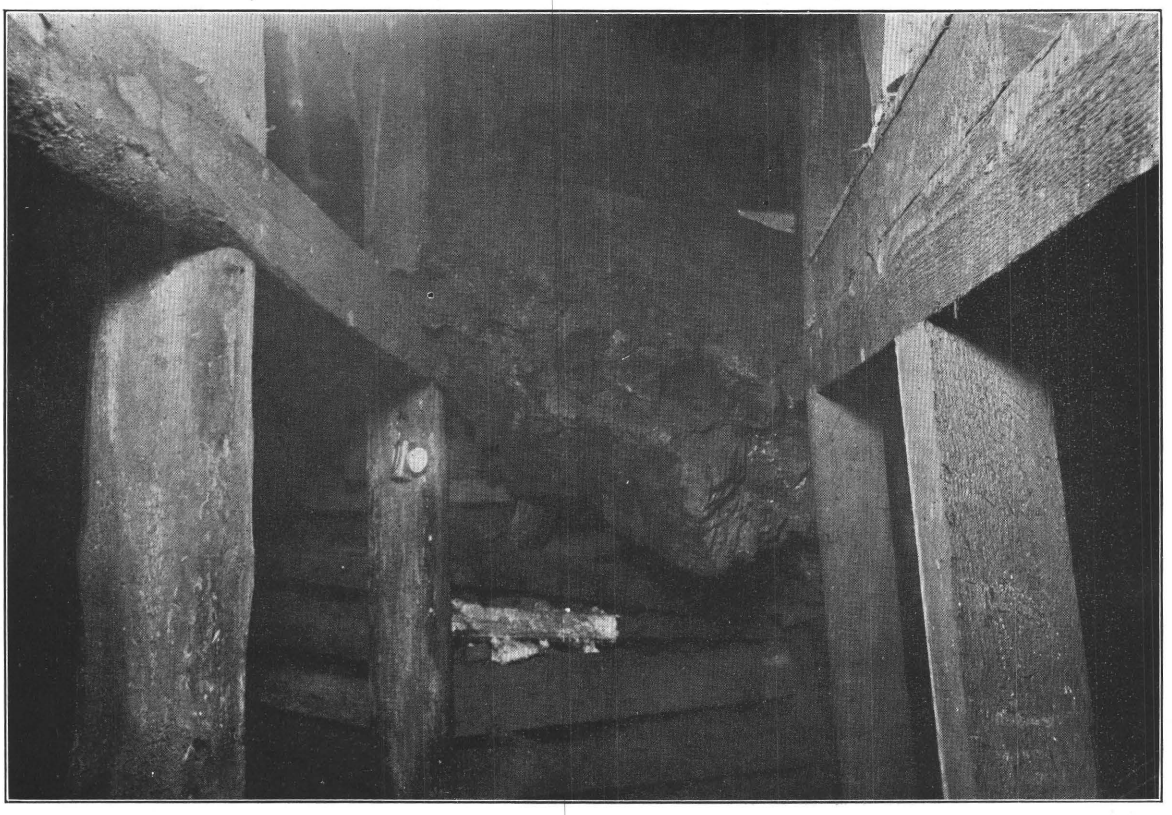
	Feet.
Cherty massive brown sandstone	12–15
Light-gray limestone, black cherts at top	4– 5
Black limestone, carbonaceous at base	20
White sandstone	7
Gray siliceous limestone with sandy beds	15
Thin banded gray shaly limestone	1½
Weber quartzite.	

Similarly in the Silver King mine the principal bedded deposits occur in a limestone member in the lower part of the Park City formation. Along the crosscut running northeast from the station on the 900-foot level the drift passes up through the Weber quartzite and the basal part of the Park City formation to the ore-bearing member. The beds traversed clearly embrace the equivalents of those noted in the Daly West, also certain beds that were not observed in that mine. The existence of many strong strike faults renders any close measurement of thickness impossible. In general it appears here and elsewhere through this property that the principal ore-bearing member is somewhat higher than to the southeast in Daly West ground, being approximately 100 feet above the Weber quartzite, as shown in the structure section through the Silver King shaft and ore-bearing member (Pl. XLIII, *A*, p. 184). The ore-bearing series here comprises a bed of fine even-grained gray siliceous limestone overlying a fine-grained grayish-brown quartzite. The ore appears to have formed in the base of the limestone over the quartzite. Above, on the 800-foot level, where the ore bed and walls show more clearly, a 3-foot bed of shaly limestone that gives way to ore lies between walls of fine-grained gray siliceous limestone. (See Pl. XXXIV.)

These selected examples in two leading mines afford the best evidence on this important feature. Variations from these normal conditions were also noted. Thus, in the Silver King mine certain beds at horizons above the main deposit are found in places to carry ore. In the Daly West mine above drift C a large stope shows double ore beds, where a layer of brown sandstone or quartzite known as the "parting quartzite" separates a 15-foot bed of ore from an underlying 6-foot bed of ore. (See Pl. XXXIII, *B*.) Again, on the '01 level west, ore

A. STOPE ON 4-FOOT BED OF RICH ORE CONFORMABLE WITH SEDIMENTARY BEDS AS WALLS.

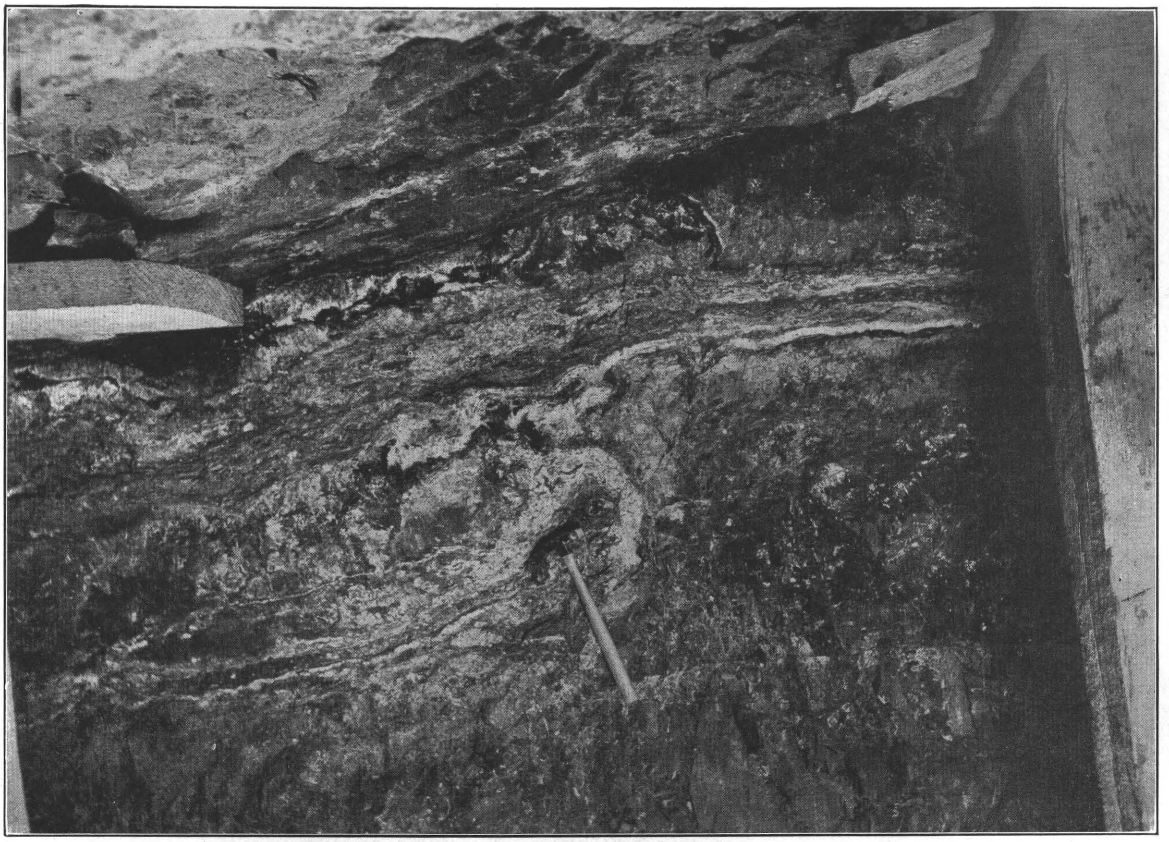
C stope above C drift, Daly West mine. Looking southwest.



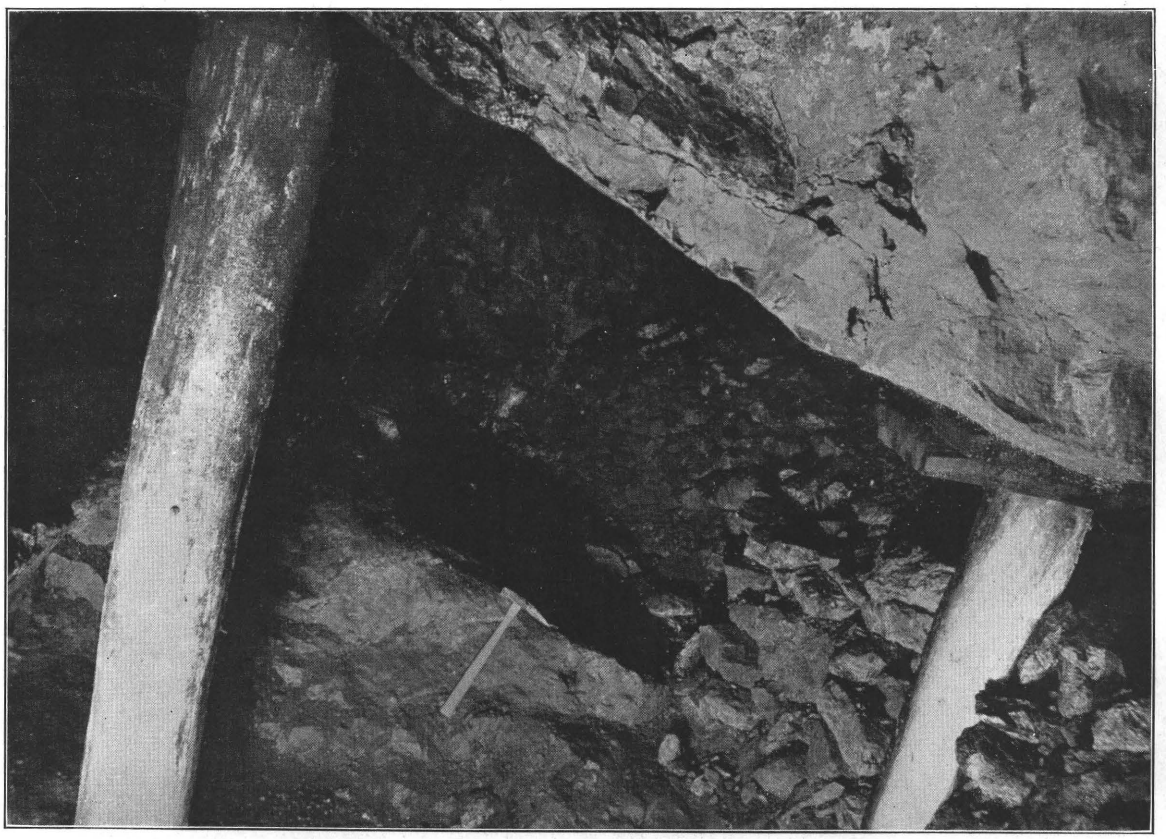
B. BARREN BED ("PARTING QUARTZITE") BETWEEN UPPER 15-FOOT STOPE AND LOWER 6-FOOT STOPE ON BEDDED ORE.

C stope, Daly West mine Looking south.

STOPES ON BEDDED ORE.



A. BED OF RICH BANDED CARBONATE ORE BETWEEN CLEAN SILICEOUS WALLS.
On 750-foot level north, Silver King mine. Looking east.



B. STOPE ON BED OF CARBONATE ORE BETWEEN DEFINITE WALLS OF SILICEOUS LIMESTONE.
Just below 700-foot level, Silver King mine. Looking west.

BEDDED CARBONATE ORE.

occurred in limestone immediately overlying Weber quartzite. These, however, appear to be exceptions to the normal habit described above.

In order to ascertain the determining factors in the selective action through which ore forms in certain beds to the exclusion of others, samples were taken from the beds in which the ore is best and from the hanging wall and footwall of those beds. The samples from the Silver King and Daly West mines are from the Park City formation and those from the Scottish Chief are from the Thaynes formation. Partial analyses of these specimens are given below.

Analyses of rock from ore beds and walls.

[Analyst, George Steiger, United States Geological Survey.]

	1	2	3	4	5	6	7	8	9
SiO_2	1.50	4.54	86.77	2.97	3.81	64.86	1.90	63.81	70.05
Al_2O_3	.31	.64	2.81	.68	.19	1.36	1.70	9.67	7.47
Fe_2O_3	.11	None.	.40	None.	.38	.46	1.62	None.	.19
FeO	.16	.30	.16	.32	.16	.13	1.40	2.17	1.17
MgO	20.41	19.07	.92	19.11	19.54	6.30	1.04	4.30	2.81
CaO	30.54	29.69	3.99	28.04	30.11	10.60	50.51	11.98	11.84
TiO_2	None.	.04	.12	None.	.....	.08	.08	.67	.52
CO_2	46.03	44.27	3.44	44.00	44.78	13.78	39.66	1.11	1.03
MnO	.28	.25	.02	.57	.....	.19	.70	.44	.31

1. Bed replaced by main bedded ore deposits, Silver King mine, stope on 700-foot level west (specimen 1126).
2. Hanging wall immediately over main ore bed, Silver King mine, stope on 700-foot level west (specimen 1128).
3. Second true hanging wall bed, Silver King mine, stope on 700-foot level west (specimen 1130).
4. Footwall immediately under main ore bed, Silver King mine, stope on 700-foot level west (specimen 1131).
5. Bed replaced by main ore bed, Daly West mine, stope A (specimen 953).
6. "Parting quartzite," barren bed between two ore beds, Daly West mine, roll incline between B and C levels (specimen 957).
7. Bed replaced by main ore bed, Scottish Chief mine (specimen 974).
8. Hanging wall of main ore bed, Scottish Chief mine (specimen 975).
9. Footwall of main ore bed, Scottish chief mine (specimen 973).

The figures showing the composition of these beds bring out certain broad facts clearly. Thus, the ore beds are seen to be low in silica and high in lime, those from the Park City formation being highly magnesian. The hanging walls, on the other hand, are high in silica and relatively low in lime, except No. 2, which was probably part of the ore bed and barren at the point of collection, the true hanging wall being No. 3. The footwalls are also high in silica and low in lime, except No. 4, which is likewise doubtless a barren portion of the ore bed instead of the true footwall. The specimens from the Scottish Chief show most clearly the high lime and low silica content of the ore bed and high silica and low lime of the walls. In brief, it appears that the ore forms best in pure or magnesian limestone and that the walls are siliceous. Two other geologic features that appear to play important parts in determining the distribution and position of ore bodies—fissures and intrusives—are considered under separate heads.

FORM AND STRUCTURE.

In general, the form of the bedded deposits is roughly lenticular, modified in various ways. Some have the length along the strike greatly extended; much more commonly the dimension along the dip is greater. The margins are as a rule irregularly lobed, some of the lobes or arms being of considerable length. The periphery is normally attenuated until it disappears. Normally these deposits occur in single or simple lenses, but some of them become compounded through the duplication of the original by others above and below.

The dimensions of the lenses differ greatly. The thickness ranges from a few inches up to 6 or even 9 or 10 feet. The maximum dimension is usually the length along the strike, which in some lenses is approximately 500 feet and in one or two is indicated by mine maps as 600 to 800 feet. The width in the direction of dip averages possibly 50 feet, reaching 100 feet in several lenses, 150 feet in the great stope at the west end of the Daly West property on the 900-foot level, and about 200 feet through a length of 600 feet in the great stope in the Silver King mine.

These features of form and dimensions were well shown in the stopes at the north end of the 750-foot level in the Silver King mine and thence down to the 800 and 900 foot levels. In the Daly West the stopes tributary to the 900-foot level west and those connected with the

sublevels above, notably the extensive C stope, afforded much valuable evidence for the above generalizations.

As the lenses of ore coincide with or occupy parts of beds of limestone, the dip and strike of these bedded deposits agree roughly with those of the inclosing limestone members. In some places entire members or beds of the limestone give way to ore. Many such beds of ore end evenly above and below on bedding planes of the overlying and underlying beds of limestone. Probably more of them, however, extend irregularly upward across the bedding, some ending in tongues or swollen surfaces and others expanding at a higher horizon to form a second ore bed (fig. 10). It thus happens that series of ore beds occur separated by intervening barren beds of limestone or sandstone. (See fig. 11.)

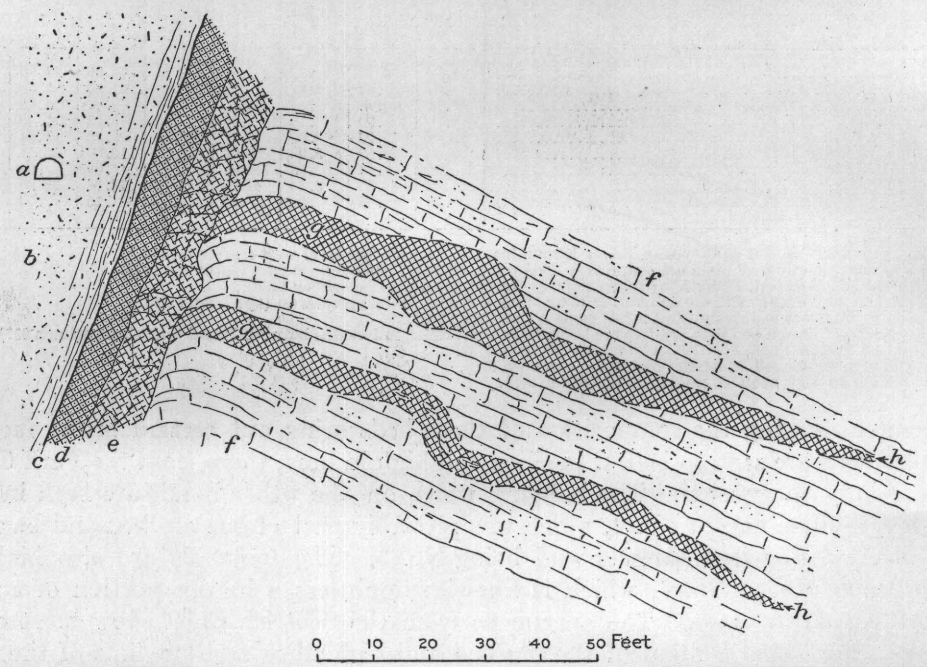


FIGURE 10.—Vein of rich lead ore in fissure between porphyry hanging wall and metamorphic limestone footwall, big stope, Hanauer tunnel, Kearns-Keith mine. Shows also bands of ore extending out from fissure along bedding and postmineral movement and alteration adjacent to fissure. *a*, Hanauer tunnel; *b*, diorite porphyry, sheeted and pyritized; *c*, hanging-wall fissure; *d*, first-class lead ore in siliceous gangue; *e*, breccia zone containing fragments of ore; *f*, metamorphosed limestone of Thaynes formation; *g*, banded lead ore, oxidized; *h*, banded lead ore, sulphide.

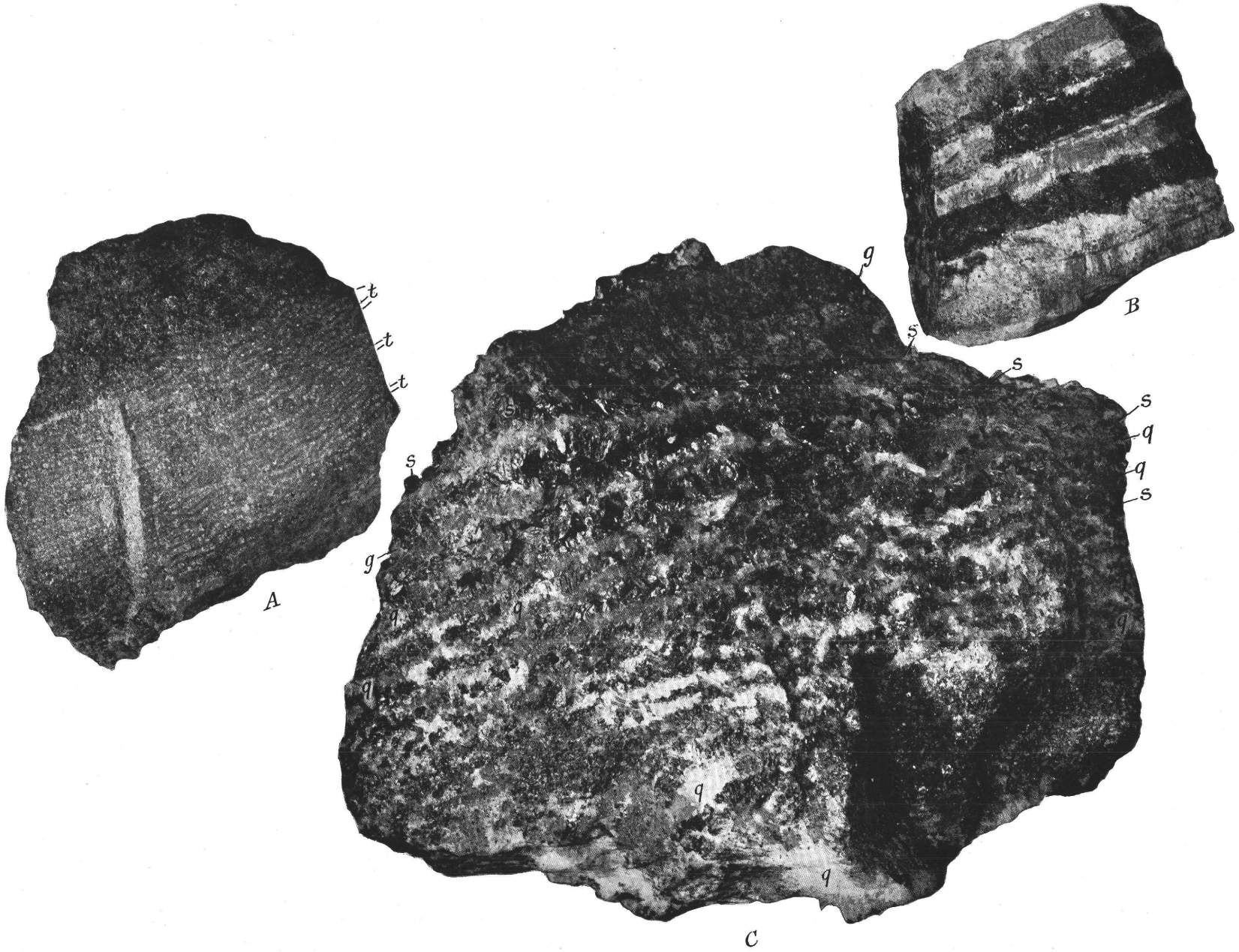
In a precisely similar manner the bed of ore is made up of layers or laminæ which correspond in all ways to the laminæ of limestone which make up the member or bed of limestone. These layers range from a small fraction of an inch up to 1 or 2 inches in thickness, according to the thickness of the bands forming the original limestone bed.

Finally, these laminæ are seen, some by the naked eye and others by the microscope, to be themselves built up of minute layers of ore. These again are seen under the microscope to be composed of interlocking grains of the several ore and gangue minerals, on a pattern similar to that of the original limestone.

Instances illustrating these features abound. Thus, in the great stope A the upper face showed a 6-foot bed of banded ore lying between evenly preserved bedding planes. This 6-foot bed was made up as follows:

Section of ore bed in stope A, Daly West mine.

	Inches.
Coarse galena, with sphalerite	8–10
Fine-grained siliceous limestone	6
Pyrite, galena, and gray copper in siliceous limestone	8
Coarse galena with white quartz	6
Massive fine-grained galena and gray copper	18
Slightly oxidized ore with quartz bands	12
Footwall sandstone.	



A. LAMINÆ OF GALENA AND TETRAHEDRITE (*t*) CONFORMABLE WITH BEDDING OF LIMESTONE COUNTRY ROCK, DALY WEST MINE.
B. BANDS OF SPHALERITE ALTERNATING WITH LAMINÆ OF METAMORPHOSED LIMESTONE, CALIFORNIA DUMP.
C. BANDED ZINCIFEROUS LEAD ORE.

Semicrystalline sphalerite (*s*) intergrown with some galena (*g*) is interlaminated with semicrystalline quartz (*q*). Banding conforms with bedding. From 1,200-foot level, Daly-Judge mine.

BANDED STRUCTURE OF ORES.

Similarly, on the 900-foot level at the west end the upper face shows a 4-foot bed of banded argentiferous lead ore between a calcareous sandstone or siliceous limestone hanging wall and a sandstone footwall (Pl. XXXIII, *A*). The banding is brought out by partings of siliceous gangue. In the Silver King mine the walls of the stope adjacent to the incline at the north end leading from the 750-foot to the 800-foot level show a 4-foot bed of well-banded rich, partly oxidized lead-silver ore between members of the Park City formation (Pl. XXXIV, *A*).

Inspection shows that the bands of ore are structurally continuous with the bands of limestone of the inclosing beds. A specimen from the California mine, reproduced in Plate XXXV, *B*, shows bands of zinciferous lead ore continuous with the bands of metamorphic limestone. Further, many hand specimens show minute banding, which seems to be inherited from the original bedding. Thus, in the ore represented in Plate XXXV, *A*, one set of bands is composed chiefly of galena and the alternating set of tetrahedrite.

In brief, the deposits of bedded ore occur in bodies of roughly lenticular form having a banded structure which is conformable with the bedding of the inclosing limestone even down to the minute laminations.

RELATION TO FISSURES.

The relation between bedded deposits and fissures is intimate and complex. Fissures have two aspects that deserve especial mention—as conduits and as faults. Some of the most important bedded bodies were observed to have strong, somewhat mineralized fissures rising through their footwalls or descending rootlike from them. In instance after instance such mineralized fissures on being followed upward through siliceous rock to limestone members were there found to pass into bedded deposits. Their part as "feeders" is most admirably illustrated on a small scale by an occurrence observed in a connecting stope below and adjoining stope C in the Daly West mine, as shown in figure 11. An east-west fissure dipping 75° S. and carrying granular carbonate ore crosses limestone beds. From this fissure ore extends outward and upward along certain of these beds. These small layers of ore thus make out from the fissure.

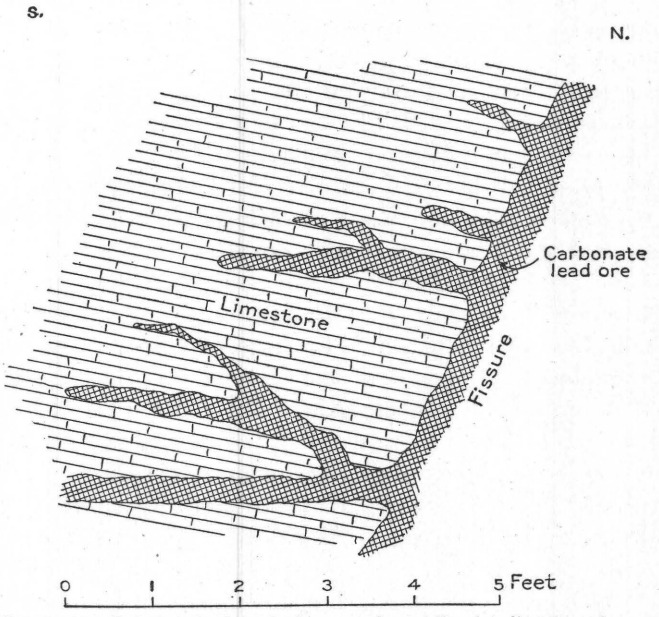


FIGURE 11.—Carbonate lead ore in fissure and extending into limestone along bedding, stope below stope C, Daly West mine. Shows fissure ore beds that replace selected limestone beds.

In a precisely similar manner, on a larger scale, the mineral-stained though lean fractures in the 900-foot level followed by the back or work drift connecting the ore chutes on the south side ascend to the great bedded deposits of the 900-foot level. Similarly, also, east-west, N. 70° W., and N. 80° E. fissures that are cut on the 900-foot level have been worked upward for 300 feet into extensive bedded deposits. Thus this zone was followed from level B up raise C to stope C, and along its strike by the drift immediately below stope C, and was found to feed the great lens worked through stope C.

Another and valuable illustration was observed in the Silver King mine, under the east-west stopes in the southwestern part of the mine adjacent to the Gillis raise. It is very clearly seen that the fractures in this ground served as conduits for the solutions which supplied the great flat overlying bedded deposit.

These few instances are so clear that they may be safely regarded as characteristic and as proving conclusively the function of fissures as conduits or feeders to the bedded deposits. The fractures which served for the passage upward of ore-bearing solutions acted also where they

extended to the surface as conduits for the downward movement of surface waters, thus facilitating the superficial alteration and enrichment of the bedded ore bodies.

The influence of fissures as faults is briefly discussed under "Effect of faulting" (p. 127).

RELATION TO INTRUSIVE ROCKS.

Evidence that intrusions played a controlling part in the formation of the ore deposits is present, but the physical relations between intrusive rocks and bedded ores are not as apparent in this district as elsewhere. Intrusive rocks, although abundant in this region, are not common here in close proximity to the great bedded deposits. The principal occurrences may be briefly examined.

A great stock of diorite extends into the district from the southwest to the gap above the Daly Judge and disappears beneath the glacial blanket covering the bottom of Bonanza Flat, and an extensive series of diorite porphyries rising from beneath the glacial blanket continues northeastward across the area, giving way at the extreme northeast to great flows of andesite. Abutting against these intrusive rocks and traversed by minor offshoots from them are the metamorphosed limestone formations in which the bedded deposits occur. In the immediate vicinity of these deposits several intrusive masses outcrop. About the head of Empire Canyon, forming the upper part of the Quincy and Little Bell spur, is an extensive mass of diorite porphyry. Dikes of the same rock appear about 125 feet south of the Quincy shaft, about the same distance west of the Daly West shaft, and beyond to the west, extending from the pond southward nearly to the Daly-Judge shaft. Diorite extends through the gap above the Daly-Judge and along the west side of the canyon. At the collar of the old Massachusetts shaft a small body of diorite porphyry crops out.

Within the Silver King area, singularly enough, not an outcrop of igneous rock was observed, although the dump at the mouth of a long tunnel up Woodside Gulch above the Silver King office shows much coarse diorite porphyry. Underground also the immediate vicinity of the great bedded deposits of the Silver King mine is singularly free from igneous rocks. Thus on the 300-foot level northeast of the shaft a small body of peridotite has been cut, on the 750-foot level there is a small sill of the basic porphyry, and on the 800-foot level about 80 feet south of the shaft a block of diorite porphyry is included in a northwest fracture. These few exposures are all the intrusive rocks encountered in the heart of the productive portion of the Silver King ground. In outlying portions, as at the extreme west end of the 1,200-foot level and at the extreme south end of the 1,100-foot level, extensive dikes of coarse diorite porphyry appear. So although intrusives were not observed in immediate contact with bedded deposits in this ground, small bodies were found in the vicinity and considerable masses within the general region.

In the adjacent Kearns-Keith ground bedded ore deposits are in immediate contact with extensive dikes of diorite porphyry. (See fig. 10, p. 124.)

In the Daly-Judge mine porphyry traverses ground in the vicinity of bedded deposits. The most notable example is the well-defined dike of diorite porphyry that has been exposed on the 1,200-foot level for a distance of approximately 500 feet.

In the Daly West and Quincy mines bodies of coarse diorite porphyry have been cut at several levels on the south side of the mines. These bodies appear to belong to a dike from 10 to 40 feet wide, which outcrops as mentioned above, traverses this ground in a general east-west direction, and apparently stands nearly vertical. West of the Quincy shaft bedded ore occurs in limestone abutting against the dike at several points, and on the west, in Daly West ground, extensive bodies of rich ore occur either in contact with or adjacent to this dike. Perhaps the clearest instance of ore in limestone beds adjacent to porphyry was found in the Daly West mine in a drift running off from the head of the Kirby raise about 700 feet west of the raise and just east of the main drift south. The Daly West dike, expanding at this point to a width of at least 50 feet, cuts limestone in which a large body of rich ore formed immediately over the porphyry. The ore, composed of massive galena, gray copper, and the alteration products anglesite, cerusite, malachite, and azurite, occurred in bands continuous with the banding of

the inclosing limestone. The limestone is somewhat altered and oxidized, the porphyry is likewise pyritized and oxidized, and both rocks at the contact show crushing, brecciation, silicification, and oxidation. The occurrence appears to be a normal intrusive contact between a diorite porphyry dike and limestone of the Park City formation, sulphide ore being found in the limestone along bedding adjacent to the porphyry and the whole mass being subsequently somewhat crushed and altered.

In brief, the facts above stated tend to show a close relation between bedded deposits and intrusive rocks.

EFFECT OF FAULTING.

The effect of faults on bedded deposits depends primarily upon their relative position and age. Obviously a fault that does not intersect an ore body can not directly affect it, and a fracture that crosses an ore body but is of earlier date can have no effect as a fault, although

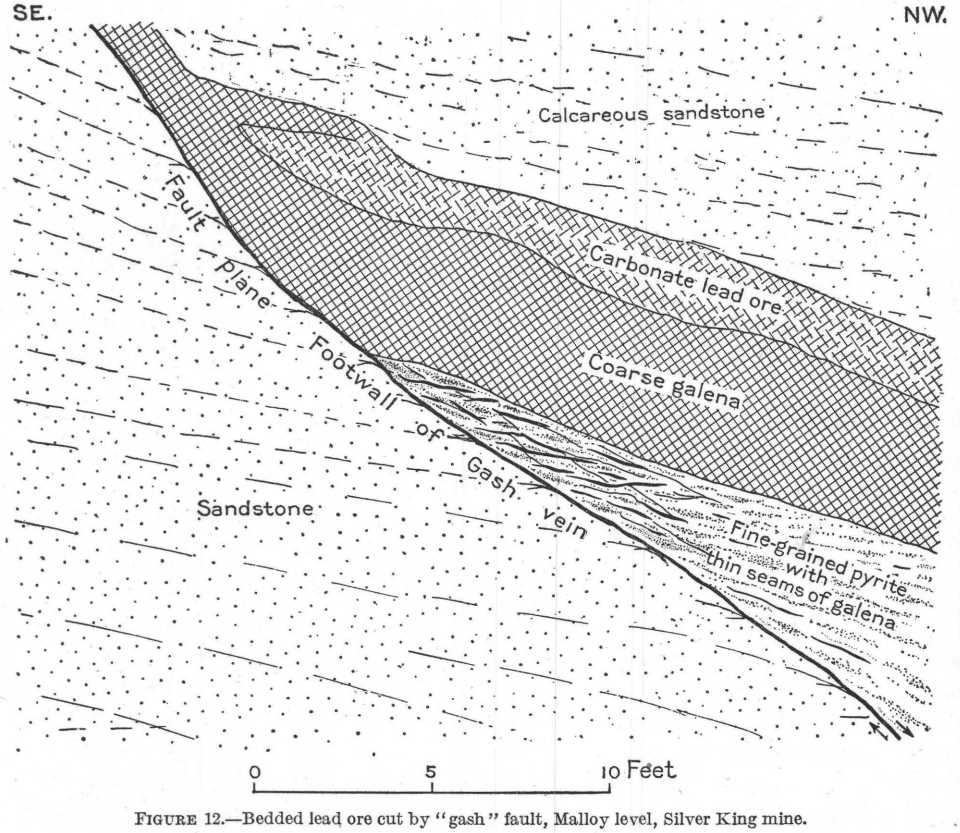


FIGURE 12.—Bedded lead ore cut by "gash" fault, Malloy level, Silver King mine.

the fissure formed by it may have served, as explained in a previous section, as a conduit for ore-bearing solutions. The faults that intersect bedded ore bodies and ore of later date displace portions of the ore bodies.

In this district ample evidence shows that faulting occurred both previous to intrusion and subsequent to intrusion and mineralization, was repeated along the same lines, and recurred along transverse courses. It is the later displacements along the old lines (commonly east-west) and the latest (commonly north-south or northwest-southeast) that are considered in this section. Examination shows that no extensive displacement of ore beds has occurred. It would thus appear that the greater part of the movement on the faults took place before the deposition of the bedded ores.

At the Daly West fracture zone the main ore-bearing bed, which has been stoped extensively from the 900-foot level up, was apparently truncated and displaced along the "roll" fault. (See detailed description of the Daly West mine, pp. 148–154.) The bedded ore on encountering

this fault is clearly bent or dragged up on the north, and fragments of ore showing crushing, rounding, and slickensiding lie in the fissure. Clearly faulting took place after ore deposition and therefore the bed of ore is displaced. The strike of this fault is east and west and where this displacement was noted it dipped 54°–70° S. The offset was at least 40 feet on the north and probably nearer 50 feet. In the stopes on this bed above to the south numerous small postmineral faults may be seen. The footwall shows many small displacements ranging from a few inches up to several feet, with corresponding offsets in the hanging wall. On the upper levels considerable faults of postmineral date have been revealed. In the same manner the ore bed in the Quincy ground is displaced for a few feet at several points.

In the Silver King mine the locus of the great bedded deposits is similarly faulted on east-west zones. None of the faults here is more important than the "gash" fracture and fortunately development has exposed ground showing its relation to the bedded ore. Thus in the stope on the flat ore body, one set above the 900-foot level and one set east of the Big chute, the "gash" fracture may be seen to cut the bedded ore (fig. 12; Pl. XLIII, *B*, p. 184). The "gash" strikes N. 60°–70° E. and descends northwestward at an angle of 60° across the bedded ore body in limestone, which dips N. 55° W. at an average angle of 21°. The bedded ore and the overlying and underlying beds of limestone end against the "gash" fault. Opposite in the hanging wall is calcareous sandstone and black carbonaceous limestone, and at lower levels quartzite lies in both walls. The bedded ore is clearly faulted. On the 900-foot level the drag in both footwall and hanging wall indicated a relative displacement downward on the hanging-wall side. Below, just above the 1,000-foot level, a drag on some ore in the footwall suggested a movement in the opposite direction. On the whole the probabilities incline toward a drop on the hanging-wall side. Similarly on the 900-foot level at the extreme north the evidence accessible tended to indicate that faulting of the same character had taken place.

These instances will suffice to indicate the essential features of the faulting on east-west fissures.

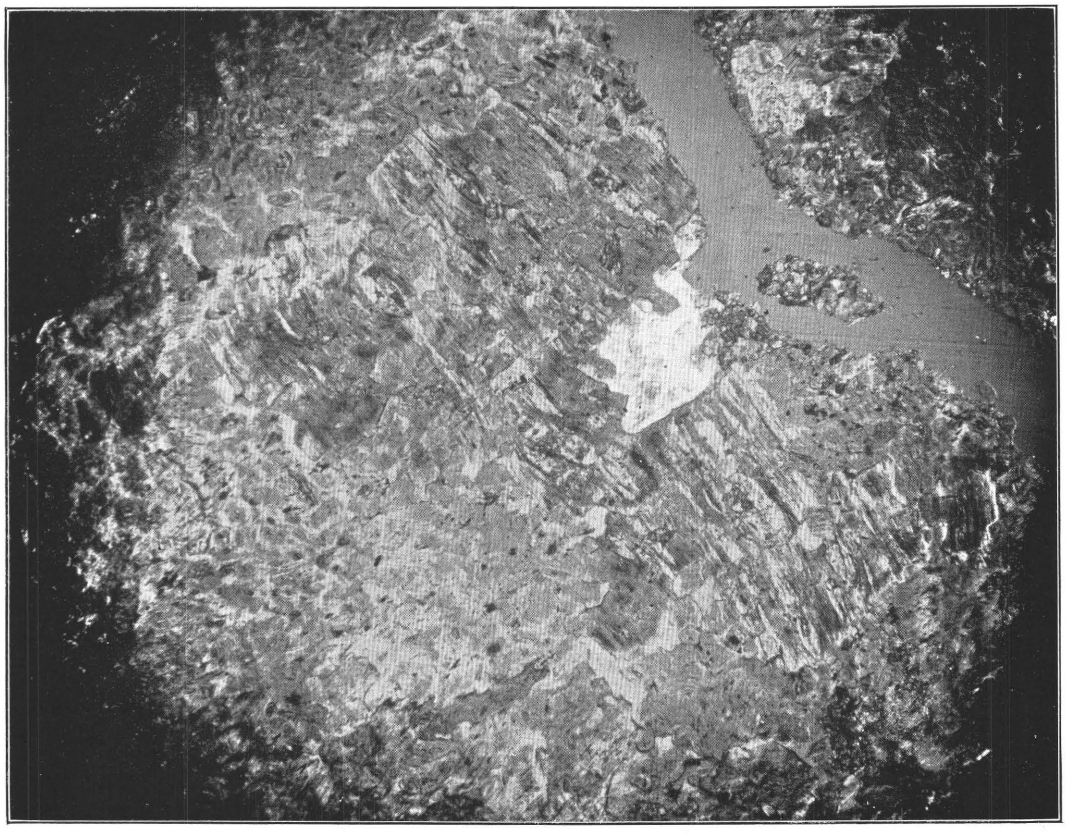
The north-south and related northwest-southeast faults are of still later date and accordingly should displace bedded ore along intersections. At several points in Silver King and Daly West ground, as well as in lesser mines, bedded ore has been displaced along north-south faults. The offsets, however, appeared to be too small to interfere with mining operations.

GENESIS OF THE ORES.

The rich lode and bedded ore bodies that have been successfully exploited here afford evidence to show that they are characteristic of their respective types. As these types have been exhaustively studied elsewhere and their criteria have been well established, it will suffice to state in the simplest form the essential points bearing on the mode of their origin.

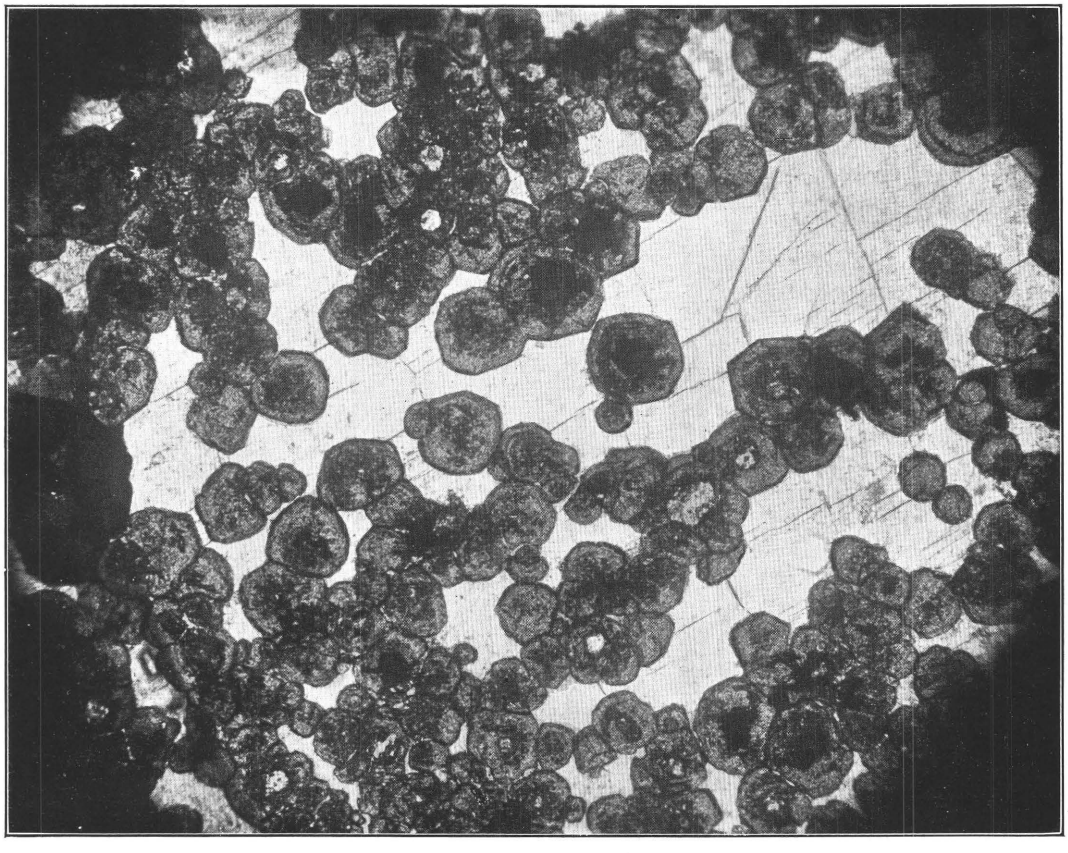
In the broadest conception the ore deposits occur in sedimentary rocks adjacent to a series of dioritic intrusives. They lie within a few hundred feet of the igneous masses and give out within a comparatively short distance from them on either side. Beyond that limit all the conditions—the sedimentary formations, the underground and surface water, etc.—continue the same, with the single exception that intrusive rocks are absent. The limit of intrusive rocks is the limit of workable ore; clearly it is a justifiable general conclusion that the intrusives were requisite for the formation of the ores.

This conclusion is fully supported on closer study of details. Thus it has been shown that along the zone of intrusives the sediments have suffered contact metamorphism, and it was seen that through this alteration certain minerals were formed that are universally recognized as due to the influence of intrusives. Along the contact (figs. 10 and 13) and intergrown with the contact minerals—garnet (Pl. XXXVI, *B*), epidote, vesuvianite, augite, and mica, in a gangue of calcite—in a manner which clearly proves that they were formed at the same time, are the ore minerals pyrite, chalcopyrite, galena, specularite, sphalerite, and magnetite. This mineral association demonstrates that the bonanza bedded ores in limestone were formed through the influence of intrusives.



A. SERPENTINE AND CHLORITE (ALTERED MICA) IN A MARMARIZED LIMESTONE, WHICH HAS BEEN SUBJECTED TO CONTACT AND HYDROMETAMORPHIC INFLUENCES.

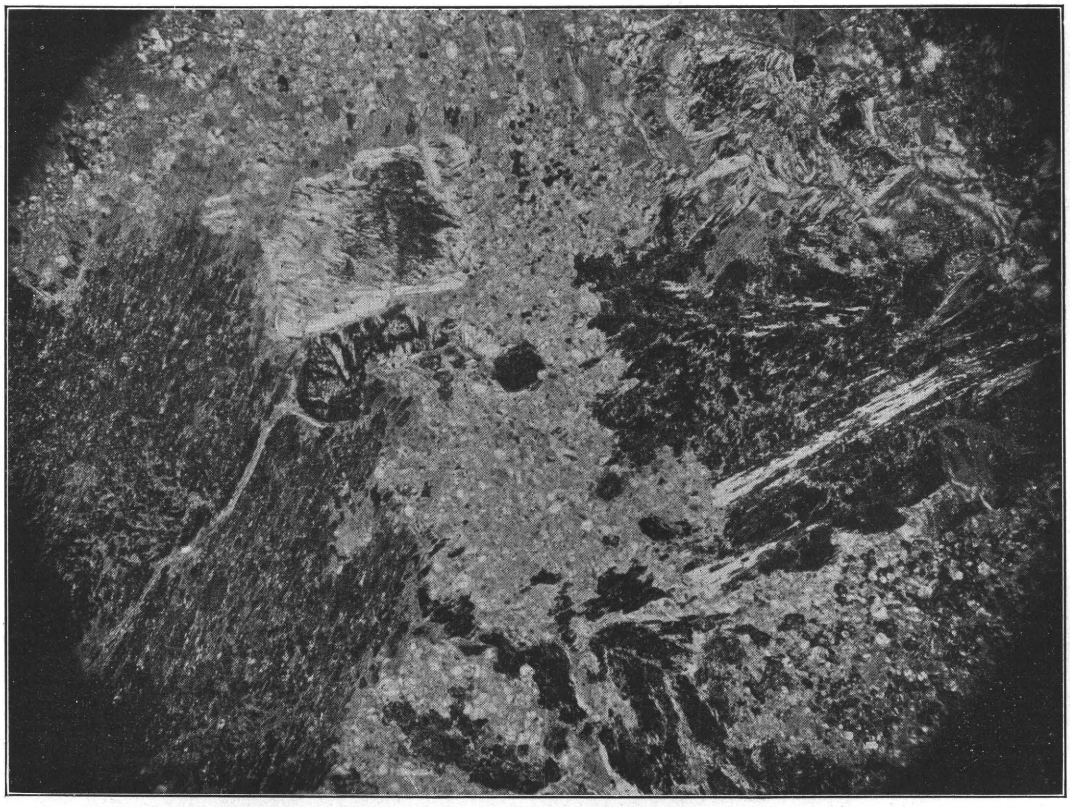
From 1,500-foot level east, Ontario mine.



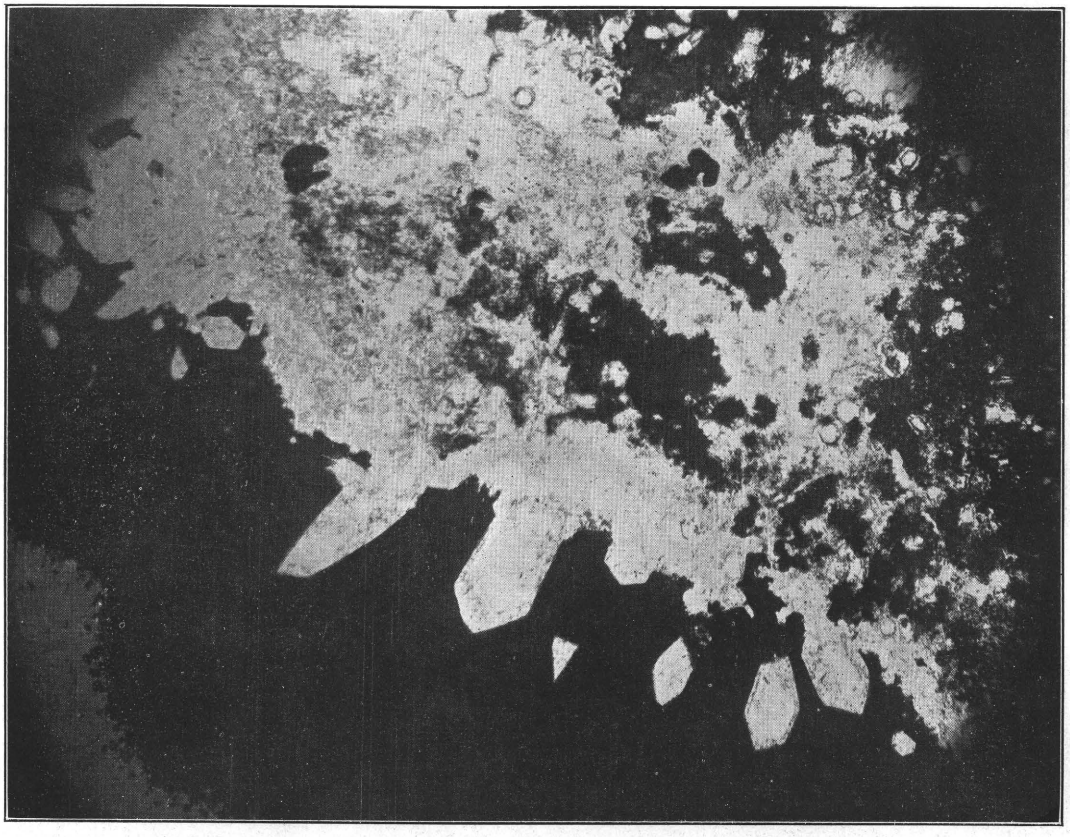
B. GARNET INCLUDING AND INTERGROWN WITH CUPRIFEROUS PYRITE IN CALCITE, IN LIMESTONE SUBJECTED TO CONTACT METAMORPHISM.

From 1,600-foot level, Ontario mine.

PHOTOMICROGRAPHS OF METAMORPHIC PRODUCTS.



A. QUARTZ INTERGROWN WITH AND PENETRATING RHODONITE (DARK AREAS).
From 1,500-foot level, Ontario mine.



B. PLATES OF BARITE ON QUARTZITE.
From dump of Flagstaff mine.

PHOTOMICROGRAPHS OF GANGUE MINERALS OF LODE ORES.

The formations adjoining the intrusive rocks are much crushed, fractured, and fissured. In certain of these fissure systems, between walls of each type of rock—quartzite, porphyry, and limestone—valuable ores formed. These were made up of about the same metallic minerals as composed the bedded ores—pyrite, chalcopyrite, galena, and tetrahedrite, with a gangue of quartz, calcite, and sphalerite. Their likeness in mineralogic composition to the bedded deposits and their close association with intrusives, whose direct connection with bedded deposits has been observed, strongly suggest that intrusives were also the causal factors in the formation of these lode ores. The excess of quartz and pyrite in the gangue and the silicification and sericitization of the walls point to the action of hot, probably alkaline aqueous solutions, such as would be expected to arise from an igneous magma. Finally, the presence of the additional gangue minerals rhodonite and fluorite indicates deposition from hot solutions or vapors ascending from underlying magmas. (Pls. XXIX, *A*, p. 112; XXXVII, *A*.)

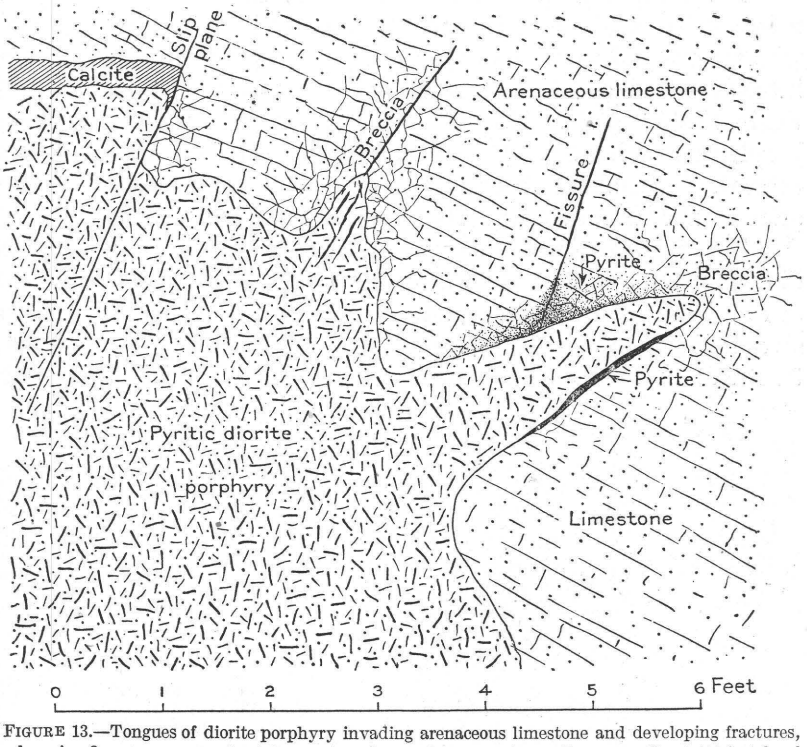


FIGURE 13.—Tongues of diorite porphyry invading arenaceous limestone and developing fractures, breccia, fissures, seams of calcite, and grains and seams of cupriferous pyrite, 1,100-foot level south, Silver King mine.

Two other facts corroborate the conclusions above stated. First, the extension of ore in fissures through a composite footwall up to a bedded deposit without continuing beyond through the hanging wall and the definite upward termination of a lode (see fig. 14) show that the direction of movement of ore-transporting agents was upward. Second, the mode of inclusion of certain isolated portions of a vein within another, as, for example, the fragments of rhodochrosite and rhodonite in a quartz core in a vein in Ontario ground (see fig. 15), strongly suggests that at least some of the transporting agents were in liquid form. Consideration of chemical composition, solubility, and temperature leads to the conclusion that these liquid solutions were aqueous.

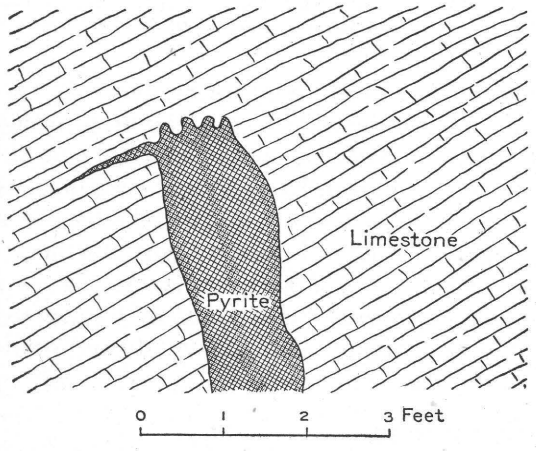


FIGURE 14.—Vein of pyrite rising through limestone, ending abruptly against bedding plane, and extending laterally along the beds, California mine, intermediate level, under stopes.

The process of deposition, as indicated by abundant evidence, was one of replacement of limestone beds and frequently of walls of fissures and to a minor extent included the filling of fissures. Thus it has been shown that the bedded deposits occupy the position of portions of beds of limestone, that the layers or laminæ which make up a bed of ore correspond in every way to laminæ of limestone which compose the limestone bed, and finally that these laminæ

are made up of grains of ore and gangue minerals arranged in a pattern exactly like that of the original limestone (Pl. XXXV, p. 124). Lode ores show similar evidence of replacement of walls and here and there comb structure indicates some filling.

It is clear that ore deposition occurred at two or more periods, which may be dated with reference to other geologic events. Some of the bedded ore was deposited contemporaneously with intrusion, but the lode deposits probably were formed later, when at least the surface of the intrusives had cooled to partial rigidity, and apparently some additions were then made to the bedded deposits. It has been shown that the diorite is not earlier than Triassic and that the porphyry is at least as late as Lower Triassic and together with the ore-bearing fissures is earlier than the "Vermilion Creek" (Eocene). Hence some of the ore deposits were probably formed after Lower Triassic and before "Vermilion Creek" time.

The facts reviewed above indicate that between early Triassic and early Tertiary time dioritic intrusives invaded this area, metamorphosed the sediments, and induced the deposition of rich lead-silver ores in certain members of the calcareous formations; that after these intrusives had cooled to at least partial rigidity, the composite country rock was broken by persistent fractures in northeast-southwest directions; that aqueous solutions of alkaline nature and

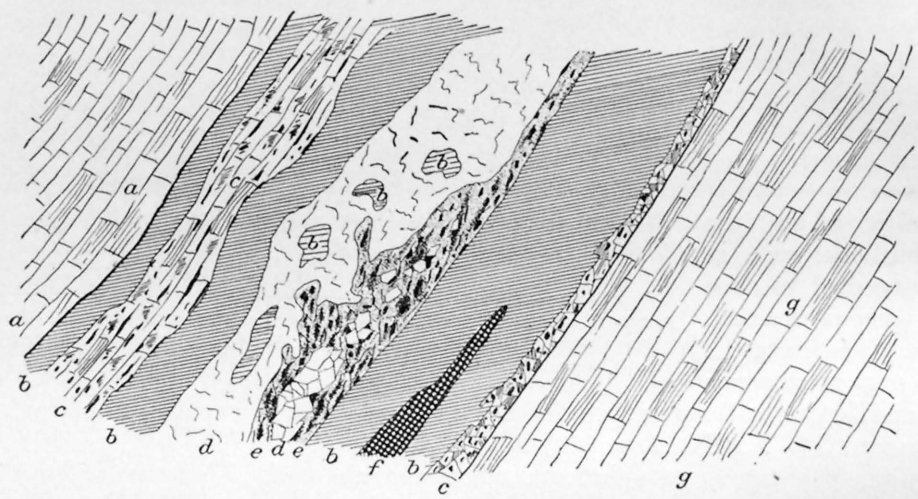


FIGURE 15.—Vein of lead and copper ore in gangue of rhodonite and quartz between beds of silicified metamorphic limestone, 1,500-foot level east, Ontario mine. *a*, Silicified limestone hanging wall; *b*, rhodonite; *c*, gray copper (tetrahedrite) with pyrite in siliceous limestone; *d*, quartz; *e*, galena, gray copper, and pyrite in quartz; *f*, solid galena; *g*, silicified limestone, with marble footwall.

some gases arising from the deep-lying, still molten portion of the magma transported ore-making elements outward toward the surface; that these were deposited, on attaining suitably lower temperatures and pressures, as lead-silver ores with associated copper and gold in the form of bedded deposits in limestone and lode deposits in fissures, by replacing certain more nearly pure limestone members along and adjacent to feeding fissures and partly by filling fissures, partly by replacing their walls; that movement recurred along these northeast-southwest fissures brecciating and faulting the ore and was followed by fracturing in a northwest-southeast direction; and that along the pathways thus formed waters descending from the surface have altered the superficial portions of the primary sulphide ores to rich oxide and carbonate ores, and that this process is still in progress.

COMMERCIAL CONSIDERATIONS.

The Park City district ranks, in these days of rapid growth of mining camps, as an old camp. The ground regarded as the most favorable has been thoroughly explored and the bonanzas have been mined from the choicest portions. Yet the developments on the deep levels of the Ontario and Daly West mines give good assurance that considerable bodies of milling ore remain. At the present time, while some high-grade ore and extensive bodies of

milling ore are being exploited, interests are being consolidated in a way which permits operations on a large scale through a single plant, evidently with a view to reducing costs so as to allow the handling of lower-grade ore. This trend in the operations of the district should bring a reliable output which on a fair market should yield satisfactory returns.

The opinion held by some persons that the bonanza ground is completely worked out is not substantiated by geologic evidence. It is true that the most promising prospects both for bonanza bodies in limestone and for rich lode deposits have been tried, but good prospects for excellent ore of both types remain. The ore-bearing limestones in the great mines, though much explored, still offer promising prospects for bodies of high-grade ore. Several outside localities also appear on geologic grounds to merit prospecting. The detailed specification of prospects does not fall within the province of this report, but certain general localities and features of broad application can be briefly stated.

Bedded deposits are more likely to be found in the ground bordering the great zone of intrusive rocks or its larger offshoots. Limestone is the most favorable rock and the Park City formation is more favorable than the Thaynes. The most promising portion of the Park City formation is a pure limestone member from 4 to 6 feet thick which lies 50 to 80 feet above the base of the formation over brown sandstone beds 25 feet thick and under siliceous limestone. Finally, persistent fractures are favorable, especially those of northeast-southwest trend. In brief, bedded deposits are most likely to occur near intrusive rocks, in limestone of the Park City formation about 75 feet above the base, adjacent to persistent northeast fissures. Lode deposits also have been found to occur chiefly within the general contact zone in strong persistent fissures trending northeast and southwest and dipping northward.

Rich bedded ore has been found at a depth of 1,000 feet and good milling ore at a depth of 1,800 to 2,000 feet. No good geologic evidence was found to indicate that ore of these types may not persist in workable grade and amount to a considerably greater depth. Laterally beyond the present limits of exploration good ground remains for prospecting for both bedded and lode ore.

Given a fair market, the Park City district may reasonably be expected to afford a good output of lead-silver ore of high grade and a large amount of milling grade, with a valuable by-product of zinc, for a considerable time.

DESCRIPTIONS OF THE MINES.

GENERAL SCOPE.

The conclusions regarding the geology of the ore deposits, which have been presented in foregoing portions of this report, are based on the observations of facts that are recorded in the following detailed mine descriptions. These are designed to afford the fullest statement of the economic geology of each property consistent with the scope of this report. Unusually favorable opportunities were enjoyed for thoroughly studying both surface and underground geology. Further, as the present survey covered a transition period in the history of the camp, when many of the pioneers were leaving, an exceptional chance to procure authentic history from original sources was afforded which never can exist again.

The descriptions are presented according to the geographic distribution of the properties in five major groups, those lying in the central, eastern, northern, western, and southern portions of the district. In each of these areas the mines are subgrouped according to the canyons in which they are situated. Each canyon group is introduced by a general description of the geography, topography, geology, and occurrence of the ore bodies of the canyon. The descriptions of individual properties treat of their situation, history, development, plant, and production and of their economic geology, including character, structure, and deformation of country rock, the croppings, form, and occurrence of ore bodies, and the character and value of the ore.

CENTRAL AREA.

GEOLOGIC FEATURES.

The great mines of this region are all located within an area about 1¾ miles square at the center of the district. (See Pls. XXXVIII, XXXIX.) Empire Canyon, leading northward, forms the axis of this central area. Ontario Canyon lies next east and Walker & Webster and Woodside gulches are on the west. All of these, including Empire Canyon, head on the main east-west divide and, converging, unite at Park City, on the northern border of the district.

In this area it seems advisable to depart slightly from the geographic plan of treatment, as consideration of properties in the same lode or at the same ore horizon in a group will tend greatly to clearness and avoid much repetition. Thus, the properties located on the great fissure system opened in the Ontario, Daly, Daly West, and Daly-Judge mines fall naturally into a single group and are described first. The descriptions of these properties, lying in both Ontario and Empire canyons, will be followed in turn by those of the mines in Ontario Canyon, in Empire Canyon, in Walker & Webster Gulch, and in Woodside Gulch. This order is that of discovery, development, and extent, and possesses the additional advantage of taking up the great mines of the central area in the order of the age of the country rock in which they lie, from older to younger.

Topographically, this central area lies on the northern slope of a prominent spur extending eastward from the main divide of the Wasatch toward the Uinta Range. It is characterized by broad spurs that descend steeply from the main divide and fall off precipitously on either side to narrow, deep canyons. The strong relief is strongest about the glacial cirques at the heads of the canyons and is somewhat softened by ground moraines in the middle stretches.

Geologically, this area, the home of great bonanzas, has been the very center of vigorous and complex activities. Roughly, it contains Weber quartzite in its eastern half, overlain in the western half by two calcareous formations, the Park City and Thaynes, and the intervening Woodside shale. These broad relations have been complexly modified, however, by extensive fracturing, faulting, and intrusion, so that the contacts are offset along great faults and the formations are broken by irregular stocks and dikes. A great zone of fracturing and mineralization passes through the central part of the area in a northeast-southwest direction. The area lies on the border and immediately north of the extrusive Clayton Peak stock of diorite, which has highly metamorphosed certain sediments. Finally, the bedrock over many acres is deeply buried under glacial deposits.

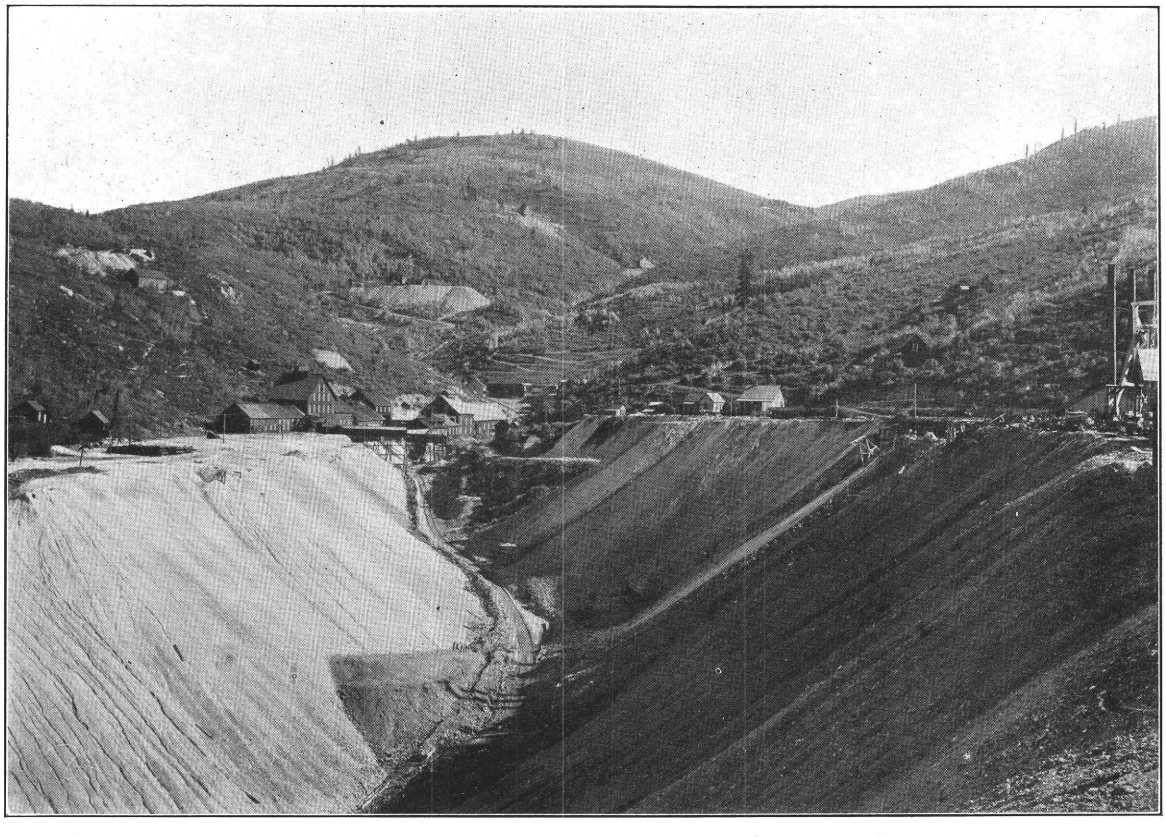
In general, westerly and northwesterly dips are characteristic of this central area, so that the successively higher formations exposed on the northwest present a rough monoclinal structure. The Weber quartzite occupies a broad spur, descending northward from Flagstaff Mountain and extending westward nearly to the bottom of Empire Canyon, and is characteristically exposed on both walls of Ontario Canyon, lower Empire Canyon, and Woodside Gulch.

The outcrops of the overlying Park City formation are irregularly distributed and patchy, owing to dislocation by faulting, interruption by intrusives, and concealment by glacial deposits. The formation appears in a rectangular area on the Quincy spur about the Quincy and Little Bell mines, but it is truncated on the south and southwest by the stock of diorite porphyry that occupies this head of the canyon and is possibly faulted and dropped along a break coincident with the bottom of the canyon. It is interrupted on the north by extensive morainal deposits, beneath which it encounters the great Ontario fracture zone and is offset to the west; thence it doubtless extends under the glacial material in the bottom of the canyon. It next appears (except for a few large blocks in float adjacent to the Daly No. 1 shaft) in the hanging-wall side of the Ontario fissure, immediately north of Daly No. 2 shaft, and apparently underlies the glacial débris on the minor spur extending north, outcropping along the bottom of the gully on the east and in the bottom of Empire Canyon on the west and also as a ledge on the west side of the canyon.

At this point it is abruptly cut by the strong zone of faulting known as the Massachusetts fault. This is best shown in the cliff in Empire Canyon at the collar of the Massachusetts

A. MINES IN ONTARIO AND EMPIRE CANYONS AND WOODSIDE GULCH.

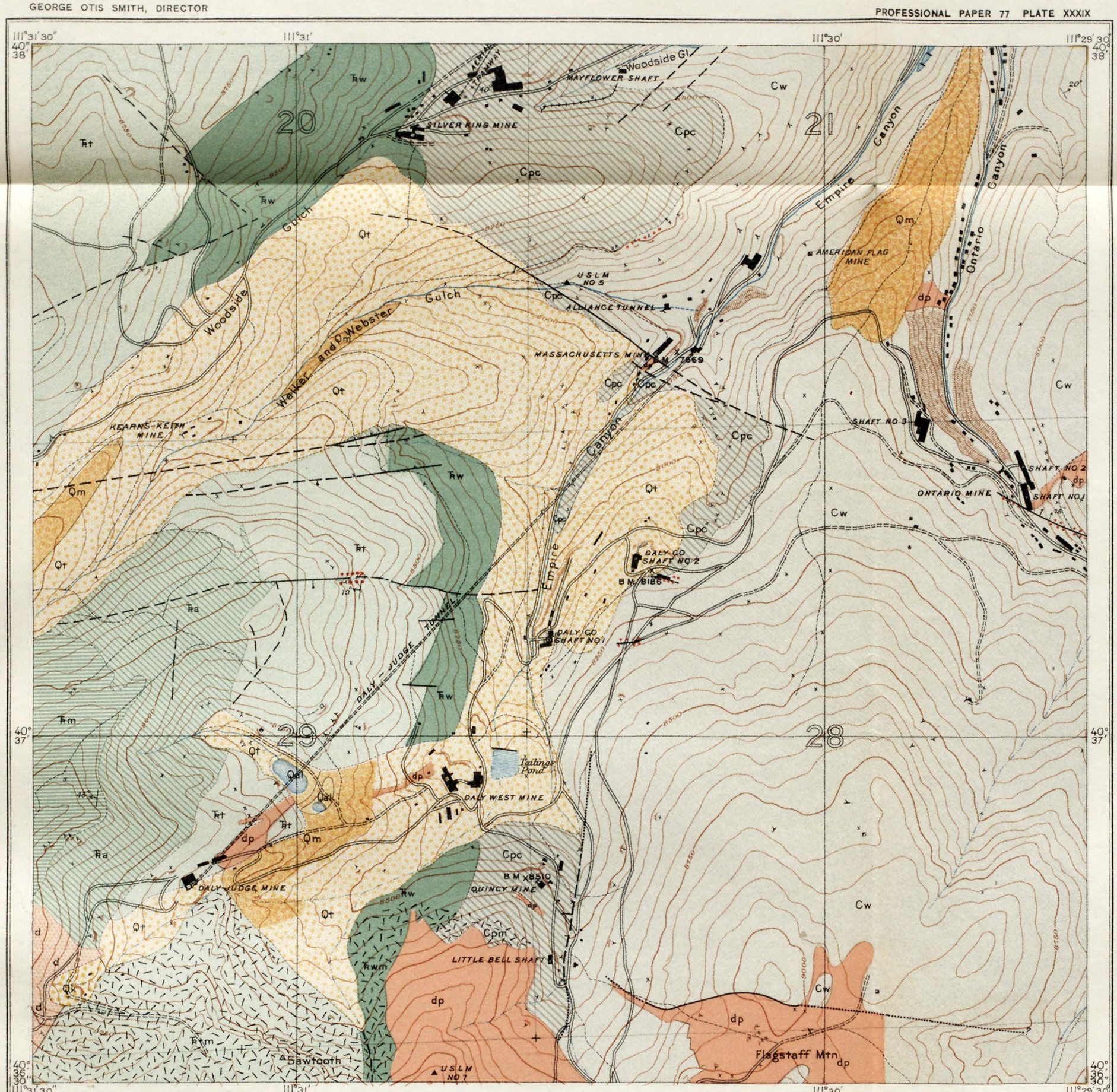
Ontario mine, Ontario Canyon, in left background; Daly-Judge, Massachusetts, Daly, and Daly West mines, Empire Canyon, in middle ground; Silver King mine, Woodside Gulch, at right. Looking southwest.



B. MINES IN UPPER ONTARIO CANYON.

Ontario mine in middle ground, shaft No. 2 at left, shaft No. 3 at right, Wabash shaft in center. In background Naildriver shaft at right, New York shaft at left. Looking southeast.

PRINCIPAL MINES IN CENTRAL PORTION OF PARK CITY DISTRICT.



GEOLOGIC MAP OF CENTRAL PORTION OF PARK CITY DISTRICT, UTAH

E. M. Douglas, Geographer in charge.
Triangulation by Pearson Chapman.
Topography by J. F. McBeth and Pearson Chapman.
Surveyed in 1901-1902.

Geology by J. M. Boutwell and J. D. Irving.
Surveyed in 1902-1903.

Scale 1/12000

0 1000 2000 3000 4000 5000 Feet

0 1/8 1/4 1/2 1 Mile

0 1000 Meters

Contour interval 50 feet.

Datum is mean sea level.

(The elevations on this map were later found to be 11 feet too high)

1912

A. HOEN & CO. BALTIMORE

LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Recent

- Qal — Alluvium

Pleistocene

- Qm — Moraines
- Qt — Till
- Qk — Kames

TRIASSIC

- Ra — Ankareh shale
- Rt / Rtm — Thaynes formation; Rtm *indicates metamorphism*
- Rw / Rwm — Woodside shale; Rwm *indicates metamorphism*
- Rm — Metamorphic sediments

CARBONIFEROUS

- Cpc / Cpm — Park City formation; Cpm *indicates metamorphism*
- Cw — Weber quartzite

IGNEOUS ROCKS

POST-CARBONIFEROUS

- dp — Quartz diorite porphyry
- d — Quartz diorite
- Gossan or vein croppings

SYMBOLS

- Known formation boundary
- Concealed formation boundary
- Probable formation boundary
- Known fault
- Concealed fault
- Probable fault
- 75° Dip of fault
- Downthrown side of fault
- 30° Dip and strike
- Shaft
- Tunnel
- Prospect
- Mine dump
- ▲ U.S.L.M. U. S. land mark

shaft, where it is seen to be a nearly vertical, clean-cut fault plane. This fault may be followed with great ease by the prominent quartzite ledges on its northeast side and the limestone in croppings and in prospect dumps on its southwest side, northwestward (N. 70° W. ?) across Walker & Webster Gulch to the point where the faulted limestone again appears on the western slope of this gulch. Its probable course may be followed farther by prominent ledges, by the topography, and by known faulting in Woodside Gulch, but its exact position is hidden by glacial débris. Possibly it is a branch of this main fault or a member of the same zone which offsets the contact of the Thaynes formation with underlying Woodside shale in the gap between the Silver King and Silver King Consolidated mines. East of the Massachusetts shaft it is seen in the Daly-Judge tunnel and in the gully farther east. The particular importance of this fault is that it solves the mooted problem of the relation of the limestone formations in which the bonanzas of the Silver King and Daly West mines occur. It is the great offset on this fault, amounting to about 2,500 feet, measured horizontally, that has led to the oft-repeated question, "Is the limestone formation in the Daly West, at the head of Empire Canyon, the same as that in the Silver King, in Woodside Gulch?" Obviously they could not be under normal conditions. On this problem the structural evidence afforded by the determination of this fault, the stratigraphic evidence obtained from detailed study and measurement in each property both on the surface and underground, and the paleontologic evidence yielded by the fauna from each property prove indisputably that the limestones belong to the same formation—the Park City. From the position on the spur above the Fairview incline, to which it has been thus faulted, this formation strikes northwestward across Woodside Gulch and thence along its western wall in Treasure Hill.

The Woodside shale, which overlies the limestone, attains within this area both its most typical and its most altered state, on the north and south borders, respectively. Thus in the main divide in the gully between Sawtooth Peak and the porphyry stock at the head of Quincy spur the normal red shale, greatly thinned by faulting and intrusion, becomes a brown, gray, and drab rusty metamorphic argillite and disappears as such beneath the heavy glacial deposits just south of the Daly West shaft. Due north of the shaft, and thus on the hanging side of the great fracture zone it outcrops below the Morgan shaft and to the north along the east slope of Morgan Knob, where it is faulted by a succession of east-west faults, apparently offshoots from the Ontario system, and then disappears beneath the heavy glacial deposits of Walker & Webster Gulch. It forms the fine full slope above the Silver King, where it appears in characteristic and fullest development.

The Thaynes formation, the second most important ore-bearing formation in the district, appears in the main divide in a highly metamorphosed state, yet with a sufficient fauna to identify it, and forms the precipitous and picturesque ledges at the head of Empire Canyon overlooking the Daly-Judge shaft. It outcrops on the north side of the main fracture zone, under the bunk house just beside the shaft, the outcrop at the east end of this building having yielded a Triassic fauna. Thence it stretches northward across Morgan Hollow and Knob, and then passes under the glacial deposits of Walker & Webster Gulch. At this point it encounters another important fault system, which will be described in full in connection with Crescent Ridge; it is sufficient at this point to state that after being offset to the west this formation continues northward above the Woodside shale.

The Ankareh shale outcrops in Walker & Webster Gulch as a thin cap over the Thaynes formation upon the west slope of Morgan Knob. It is highly metamorphosed on the south, in the vicinity of the tongue of diorite that occupies the gap above the Daly-Judge.

Intrusion, fracturing, and glaciation play important parts in this area. Intrusive stocks outcrop at the crest of Flagstaff Mountain, east of Empire Canyon. Immediately adjacent to the mines small dikes appear in the rear of Ontario shaft No. 1, just south of the Quincy shaft, west of the Daly West shaft, and east of the Daly-Judge, and bodies of porphyry have been encountered in prospects several hundred feet west of the Silver King.

The fracturing took place at several periods after the date of intrusion, some of it before the deposition of ore and some subsequently. The principal zone trends across this central

area in a northeast-southwest direction and dips steeply to the northwest. It has been richly mineralized and opened through the Ontario, Daly, Daly West, and Daly-Judge mines. Strong fracturing and faulting occurred in northwest-southeast and east-west directions, as shown by the Massachusetts fault system and the Crescent Ridge system. Finally, local glaciers deposited considerable masses of waste about the higher heads of the canyons and along their bottoms and sides. Thus it happens that an area of extreme commercial importance, that of limestone of the Park City formation in the vicinity of the Daly West mine and between that property and the Silver King, is thickly covered with glacial débris.

The ore bodies developed through the great mines of this area comprise both veins and tabular replacement bodies. The great fissures of the Ontario-Daly West system have afforded rich argentiferous lead ore, and in the limestone in the Silver King, Daly West, and Daly-Judge mines bonanzas have been found as extensive replacement beds. The occurrences in this area belong to one of these two types.

ONTARIO AND EMPIRE CANYONS.

ONTARIO FISSURE SYSTEM.

A great system of fracturing and fissuring extends through the center of the district in a northeast-southwest direction, with a prevailing dip to the northwest. The main fissures are grouped within a zone a few hundred feet wide, though numerous minor fissures occur on either side. In this zone six or eight fissures have been found to carry ore, and two, the Ontario and the Daly-Daly West lodes, have been extensively opened and found abundantly productive.

Among the topographic indications of this remarkable zone is the broad spur between Ontario and Empire canyons, whose slope changes from a steep to a flat angle along the line of the zone. The striking alignment of the canyon from the Daly West to the Daly-Judge with the gap beyond is with little doubt due in large measure to weakening by crushing along this zone, and the several gullies on the western slope of Empire Canyon, just west of the Daly shafts, mark faults which extend westward into the hanging wall of the main Ontario lode.

The geologic and mineralogic indications of this zone are even more distinct. The rocks traversed by it are those quartzites which form the greater part of the Weber quartzite and on the southwest the overlying Park City formation, Woodside shale, and Thaynes formation. On the east side of Ontario Canyon the Ontario lode outcrops as a distinct fissure with slickensided walls of quartzite rusted and stained greenish yellow and black. Similar evidence of this lode was found near the Daly No. 2 shaft. On the southwest this great zone of fracturing enters the limestone and shale formations overlying the Weber quartzite. The very apparent offsetting due to faulting along the zone affords additional surface proofs of its position.

This main zone was the object of operations in the earliest days and has since that time been constantly and extensively developed. The first work on it was done in 1872, when the Ontario was opened in the east side of Ontario Canyon. It was then developed progressively westward and deeper in Daly, Daly West, and Daly-Judge ground until to-day the combined workings of these adjoining properties, aggregating many miles, are among the most extensive known. The greatest depth in a single property has been reached in the Ontario mine on the 2,000-foot level. This is 2,950 feet below the collar of the Daly-Judge mine, in which are the highest workings on the zone. (See fig. 16.)

The main zone has been opened through these properties for a length of about 2 miles, the Ontario vein for 5,500 feet, and the Daly-Daly West for 1,000 feet. In addition to this long and deep stretch of workings is the Ontario drain tunnel, which extends from the east end of the Ontario mine eastward under Bald Eagle Mountain and discharges 3 miles distant at the base of the eastern slope of the range. At the southwest also, where this main zone enters the overlying formations, the limestones have been extensively explored. Thus the Daly West was opened for its lode ores, but was later operated mainly for the great bonanzas in the limestone, and recently has yielded chiefly lode ores. The adjoining property on the west, the Daly-Judge, has developed extensively the lode which in the Daly West has proved so productive, but the principal source of its output has been the ore bodies in limestone.

The chief sources of ore in the fracture zone have been the Ontario lode and the Daly-Daly West lode. They are both strong ore-bearing fissures (locally the zone of fissuring and fracturing), dipping steeply northward and striking northeast and southwest in sedimentary and intrusive igneous rocks. Both are faults on which the hanging wall has dropped, that of the Ontario fissure near the No. 3 shaft about 230 feet. The country rock for the greater part of their courses is Weber quartzite. In the Ontario, however, interbedded or underlying limestone forms the footwall below the 1,330-foot level and the hanging wall below the 1,560-foot level. In the Daly these interbedded limestones are cut, and in the Daly West overlying limestones and carbonaceous calcareous beds of the Park City formation form the hanging wall throughout, from the 900-foot to the bottom level. In the Daly-Judge mine limestones of the Park City and probably of the Thaynes formation lie in the footwall, and the Thaynes formation (possibly) and Woodside shale in the hanging wall. The intrusive rocks encountered, mainly irregular dikes and stocks of diorite porphyry and some granular rocks of the same general composition, are without exception older than the lodes, being indiscriminately cut by them. Structurally the Daly-Daly West lode is the principal one of a group which may be regarded either as a series of branches from the Ontario lode into its footwall toward the southwest or as a parallel en échelon series united with the Ontario lode by oblique transverse lodes. The main exception to this general character of the lodes in this zone is the so-called "back vein" in the Daly West and Daly-Judge mines, which dips to the southeast.

The bonanzas of the Daly West occur in a particular limestone member of the Park City formation which lies about 30 feet above the Weber quartzite and immediately over a thin interbedded quartzite layer. In the Daly-Judge the ore bodies have been found both in fissures in this bonanza-bearing limestone and at several other horizons in the Park City formation.

The lode ores carry silver, lead, and iron with zinc. The shallower parts, notably about the 600-foot level or from the 200-foot to the 1,050-foot level in the Ontario, have proved richest. Zinc and iron have increased in depth and toward the southwest. The bedded ores in limestones in the Daly West mine gave high yields of lead and silver with some copper and gold. The gangue of both classes of ore is siliceous. Thus

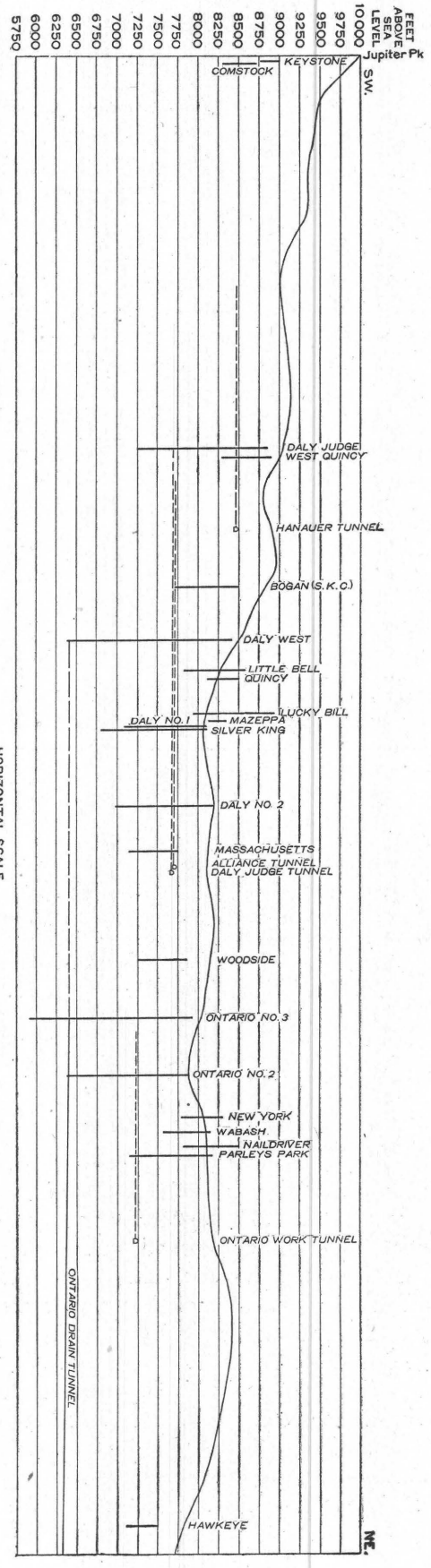


FIGURE 16.—Profile section along line of Ontario drain tunnel from adit southwestward to Jupiter Hill, showing principal shafts and tunnels in actual and relative elevation.

the bedded ores and the higher-grade portions of the lode ores were suitable for shipping direct, but by far the greater part of the lode ores requires concentrating, from 4 to 6 into 1, before reduction.

The above sketch of the great mines situated upon the Ontario fracture system shows their resemblances in geology and in mode of occurrence and character of their ores—in short, their unity. Such a unity requires for the cheapest, quickest, and best operation that these several properties be consolidated and operated as a single great mine.

ONTARIO MINE.

SITUATION AND HISTORY.

The Ontario mine is situated due south of Park City, in Ontario Canyon $1\frac{1}{8}$ miles above its mouth.

The Ontario lode is generally believed to have been discovered by Rector Steen and his associates John Kain and Gus McDowell in 1872. Accounts relating to the date and manner of discovery of the Ontario differ materially. Written data kindly supplied by Mr. Steen, are authentic. A sketch quoted by the Salt Lake Herald as written by Supt. Chambers and other data have been here utilized. Mr. Steen's account is given on page 20. He and his partners sold the mine to Hearst and Stanley.

The statement credited to R. C. Chambers, who was manager of the Ontario from the purchase of the property until his death in 1901, was made from the point of view of the purchasers, and as given in the newspaper differs somewhat from that of the discoverer.

> The Ontario was discovered accidentally * * *.
>
> Herman Budden and a Missourian who went by the name of "Pike" [Rector Steen was nicknamed the Pioneer and probably Pike] and another party were prospecting in the vicinity. Budden was coming down the hill, carelessly striking the rocks with his pick as he passed along to his work farther on. He struck what he supposed to be a loose rock, and as a piece flew down the hill he thought it looked like chloride. He retraced his steps and struck the piece several times, finding that it was rock in place and really chloride ore. He had found the cropping of the ledge, a piece not larger than the top of your hat, and the only cropping of the lode that was ever found on the surface. Budden commenced digging and was soon delighted with the sight of ore. With his partners he then located the ground, calling it the Ontario, January 19, 1872, and started to prospect it by sinking a hole and running a cut on the line of the lode. At this time George Hearst and John Gashweiler, of San Francisco, were here looking at the McHenry mine, upon which San Francisco parties had a bond. They were returning disgusted with the mine, when they met Marcus Daly at what is now Lake Flat. Daly had seen the Ontario prospect with Robert Walker and at the time was returning to Little Cottonwood. He told Hearst that it made a fine showing and urged him to go down the hill and look at it. Hearst did look at it, and was pleased with it. He returned to Salt Lake and meeting me, called my attention to it and asked me to watch it. At this time James F. Berry, an old Salt Laker, and Al Guiwitz had a 30 days' bond on the prospect for $30,000. During the life of this bond I came out and examined the prospect and liked it very much. A few days before the expiration of the bond I sent George Munroe out from Salt Lake to get a 10 days' bond, commencing at the expiration of the former one, and for the same amount. He succeeded in doing this and transferred it to me, and he reported also that the prospect continued to improve. I telegraphed to Hearst to come up at once from San Francisco. After his arrival, August 23, I came up and looked over the prospect, sleeping that night under an old pine tree near the discovery. I was satisfied with the outlook, and the next morning told the boys to come along with me to Salt Lake and they could get their money. They went, and that day, August 24, the sale was made.

This mine was not, it should be recalled, the first opened in this district. In 1870–71 the Flagstaff, Piñon, Pioneer, Buckeye, Walker & Webster, Wild Bill, and Rocky Bar were discovered. In 1872 the McHenry created the interest which caused it to be visited by the men who, while on that errand, inspected and subsequently purchased the Ontario. The Ontario was, however, the first mine to be extensively developed, and for many years the history of this mine constituted the history of the camp. The "Ontario mining claim and mill site" was the first official survey recorded from the Uinta mining district. This survey was approved on December 21, 1872.

The "discovery" was situated on the east side of Ontario Canyon, a few hundred feet east of the present road and immediately east of the north end of the present office and boarding house. The lode was first developed by sinking a shaft about 100 feet east of the "discovery" and another about 250 feet west. The latter revealed an excellent showing but at the depth of 60 feet encountered water in such quantities as to render further sinking with windlass

impracticable. A tunnel was then started from the bottom of the canyon and run east along the vein in ore which averaged $250 a ton.

By the second year, 1873, the vein had been opened for 740 feet along its strike, three shafts had been sunk to depths of 98, 100, and 123 feet, and a large amount of high-grade milling ore had been developed. The No. 1 shaft started in the fall of 1873 had reached by the fall of 1874 the 300-foot level, exposing as it progressed more and more favorable prospects. On reaching the 400-foot level by the last of the year and the 500-foot level later the best exposures of ore yet seen were found. On the 500-foot level a body of high-grade ore was opened which continued without a break for the entire distance explored—a reserve valued at $1,000,000. This showing led to the renting of the McHenry mill in 1875,[1] and the so-called "chloride" ores were treated in this mill and the "base" ores were shipped to Liverpool for reduction. The following year the Marsac mill was rented and used until 1877, when a new 40-stamp amalgamation mill was completed. This was erected at an original cost of $325,000 and is the same mill which has been remodeled and refitted for use at the present time.

In December, 1876, the company was organized and incorporated with a capital stock of $10,000,000. Up to this time the property had yielded $1,100,000 and was the largest annual producer in the territory.

In 1878, owing to the fact that the No. 1 shaft was too near the lode for safety and too small for operating at depth, the No. 2 shaft was sunk to the 600-foot level. Subsequently, in view of the promising character of the lode where opened by a crosscut on the 600-foot level, also at successively lower levels, the shaft was continued to the 1,500-foot level, which remained its bottom. This sufficed for working out the eastern part of the lode, but as development proceeded westward it became too distant for the most economical exploitation. Accordingly in 1881 the No. 3 shaft was started 1,000 feet farther west and on the west side of the canyon. This was extended to a depth of 1,000 feet by 1883, at a cost, including that of hoisting works, of over half a million dollars. It reached a depth of 2,000 feet in 1903 and is at present the base of mining operations on this property.

The great flow of water encountered at a depth of 60 feet beneath the surface was not exceptional, and the particulars regarding the problems of drainage and their solution in this mine are given under "Drainage and ventilation," on pages 24–26.

The policy of development has been to keep the reserves opened at least two years ahead and to work out the lode cleanly from higher to lower levels. In accordance with this policy the upper levels have been stripped of ore, the No. 3 shaft has been sunk lower and lower and levels led off therefrom, and the territory from that point to the Daly property has been explored. Thus in 1903 the levels above the 600-foot were considered worked out and the work shaft was sunk to a depth of 2,000 feet. The lower 300 feet was in loose ground and serious difficulties were encountered not only in keeping this portion in shape to permit the passage of the cage, but even in keeping it open at all. The lode was opened on the 1,700-foot level for a length of over 2,500 feet, and inclines were driven connecting this level with the 1,500-foot both east and west of the shaft. The lode was also opened for over 1,000 feet on the 2,000-foot level, which was connected with the 1,700-foot by an incline west of the shaft.

The cost of these extensive operations was enormous, being practically two-thirds of the earnings. The production assumed large proportions from the outset, reaching in the late seventies over 1,000,000 ounces of silver annually and aggregating over $1,000,000 before 1877. In the early eighties the annual returns of the property were over $2,000,000; in 1881 the total production had amounted to over $9,350,000 and the dividends to $3,925,000. It continued to be the greatest producer in the State and the foremost silver mine in the West for several years. By 1888 the dividends paid had amounted to $8,825,000 and no assessment had ever been levied. In the late eighties the activities on this property gradually decreased, though it still maintained a large output and paid regular dividends. During the silver crisis in March, 1893, little ore was hoisted and none shipped, but in July, when all the other large mines closed, the Ontario and the Daly continued work. Dividends, however, were passed for three years,

[1] See detailed sketch on "Concentration," p. 28.

and finally, in October, 1897, the property was closed. From June to December, 1898, the tailings from the large dump below the Ontario mill were worked over in the Marsac mill at the rate of 85 tons a day with satisfactory result, and in 1899 the Ontario siliceous ore received similar treatment. In 1900 mining operations were regularly resumed and siliceous ores were treated at the Marsac mill until May, 1901, after which they, in addition to base ores, were sold to the American Smelting & Refining Co. In 1902 it was decided to sink the No. 3 shaft 300 feet deeper, to the 2,000-foot level, and to open the vein at that depth. As a result of the disclosures thus made it was decided to remodel the old Ontario mill and refit it for modern wet concentration. Pending the completion of the mill mining operations were diverted from taking out ore to exploration. In December, 1903, the mill was started on ore from the lower levels, and it has run with fair regularity since then.

A number of accidents and difficulties have handicapped operations in recent years and caused serious expenses. Among these were the difficulties encountered in sinking the deepest part of the working shaft and keeping open the excessively wet 2,000-foot level in bad ground, and the burning of the hoisting plant at No. 3 shaft in the spring of 1903, which necessitated the abandonment of pumping and caused flooding up to the 1,500-foot level. In 1904 a contract was made for extending the 1,500-foot drain and work tunnel to the Daly West property, to enable the Daly West Co. to explore and work its ground to that depth by utilizing the tunnel for draining. The terms of the contract were that the work in Ontario ground should be done at the expense of the Ontario Co. and that the Daly West Co. should extend the tunnel from the Daly-Daly West line to a point most advantageous for its workings and should pay a rental to the Ontario and Daly companies of $750 a month.[1] Two 2-man machine drills were kept working at the face of the tunnel for three shifts, despite an excessive flow of water. In the fall of 1905 a large cave in the drain tunnel took place, followed by others, which resulted in again drowning the lower levels. Difficulties were experienced in reopening the tunnel, but at last writing prospects were good for accomplishing the task.

At present the property of the Ontario Silver Mining Co. embraces the Ontario mine, with an extensive tract of land covering the workings of the two drain tunnels, a concentration mill, an electric-light plant, a two-thirds interest in local water rights, a controlling interest in the Daly Silver Mining Co., and coal mines in Weber Canyon operated under the title of the Weber Coal Co.

DEVELOPMENT.

This property has been more extensively developed than any other in the camp. Situated lower than the other properties on the great fracture zone, its workings are the deepest, as well as the easternmost, on the Ontario-Daly West lode system. The Ontario lode has been uncovered at the surface for several hundred feet by trenching. It has been opened to a depth of about 2,200 feet and for a distance of 4,800 feet along the strike. The principal workings are three deep shafts and a series of levels run at 100-foot intervals from the surface to a depth of 2,000 feet on the Ontario lode and on two strong spur veins striking southwest. There are also numerous connecting inclines. The mine is operated through the No. 3 shaft, by which ore is raised to the 600-foot level and trammed thence through a large work tunnel 1 mile northward to the mouth of Ontario Canyon, where it is delivered at an ore-shipping depot or to a concentration mill near by. This work tunnel has been extended into adjoining properties on the southwest for use in shipping their ores out and their coal in, the extension going through a footwall drift under and parallel to the main lode. On this same level, which is the most extensive in the mine (see Pl. XXXI, in pocket), footwall country rock has been explored through a crosscut for about 1,700 feet. The greatest single piece of development is the drain tunnel at the 1,500-foot level, which passes through the entire length of the mine proper in the footwall of the main lode to the No. 2 shaft. The total length of underground workings in this mine, exclusive of the many inclines and stopes, is about 50 miles.

[1] Bamberger, J. E., Report of Daly West Mining Co. for the year ending Dec. 31, 1904, p. 3.

PLANT.

The present plant of the Ontario Silver Mining Co. at the mine includes boarding and bunk houses, an extensive and complete machine shop, a hoisting outfit, a blower equipment for mine ventilation, a sawmill, etc. The mill, which is situated at the mouth of Ontario Canyon, about 1 mile north of the shaft, has been remodeled and thoroughly equipped with modern machinery for wet concentration. This has been described in detail under "Concentration" (p. 32). The plant for generating power for the electric lighting of this property and of Park City has also been described in detail on pages 22–23.

PRODUCTION.

The Ontario mine yielded 37,619,047 ounces of silver from 1877 to 1904, inclusive, from which dividends amounting to $13,936,950 were declared. The annual output is shown in the following table compiled from reports of the Ontario Co., and additional data kindly supplied by Mr. C. L. Rood, manager:

Production of Ontario mine.

Year.	Ore, net tons.	Tailings, net tons.	Silver, fine ounces.	Sold for—	Dividends.
Prior to Jan. 1, 1877				$900,000.00	
Jan. 1, 1877, to Nov. 30, 1883	112,506		10,280,537.37	11,479,736.82	$5,075,000.00
Nov. 30, 1883, to Dec. 31, 1884	24,584		2,067,803.49	2,213,728.70	975,000.00
1885	30,953		2,353,528.79	2,294,219.64	975,000.00
1886	30,044		1,898,035.54	1,694,088.35	900,000.00
1887	33,815		2,023,061.87	1,794,192.08	900,000.00
1888	36,566		1,963,514.46	1,701,140.37	900,000.00
1889	36,459		1,971,766.71	1,662,166.86	900,000.00
1890	36,570		1,840,141.76	1,768,020.06	900,000.00
1891	37,818		1,873,503.75	1,662,804.89	900,000.00
1892	37,868		1,738,396.50	1,320,198.50	750,000.00
1893	29,642		1,198,218.15	867,499.84	
1894	29,550		1,346,291.45	856,711.58	
1895	31,106		1,348,644.88	897,149.84	
1896	30,802		1,191,672.58	776,853.67	180,000.00
1897	23,897		904,435.37	538,183.51	202,500.00
1898	3,102		229,034.69	117,088.04	
Tailings, 1898		11,919	101,446.41	66,793.44	
1899	10,247		607,237.22	288,090.97	15,000.00
Tailings, 1899		15,366	113,152.58	76,225.84	
1900	23,266		923,583.15	539,336.88	90,000.00
1901	30,326		1,189,485.92	499,371.42	90,000.00
Tailings, 1901		7,170	71,171.00	42,349.48	
1903	463		22,858.32		10,658.25
1904	23,910		361,525.93		173,791.88
Total	653,494	34,455	37,619,047.89	34,055,950.78	13,936,950.13

ECONOMIC GEOLOGY.

Character of country rock.—The rocks in which the Ontario ore bodies have been found belong mainly to the Weber quartzite. Some diorite porphyry has also been cut and on the lower levels the lode traverses limestone. The surface geology of the Ontario property is simple. The outcrops in the region of the mine proper are almost entirely massive, heavily bedded Weber quartzite. Intrusive rocks outcrop in two small areas, one, a narrow, irregular dike, which cuts across the quartzite from the rear of the No. 1 shaft house into the gap immediately east, and another dikelike mass which appears at the north end of the No. 3 dump. Along the back of the spur between Ontario and Empire canyons heavy glacial deposits of mixed sedimentary and igneous material extend northward from a point opposite the No. 3 dump.

Underground the upper two-thirds of the mine is in Weber quartzite and the lower third in limestone or marble. The superficial portions of the quartzite are broken, stained, and altered, but the deeper part is more solid, fresher, and firmer. The limestone is dense, well banded, and colored blue and black except that in various stages of metamorphism, which approaches and in some places becomes white marble. Its features are well exhibited on the 1,500-foot level, the black limestone being cut in the drain west of the No. 3 shaft and the banded rock appearing characteristically at the main vein east of No. 2 shaft and followed from the east drain. On the 1,700 and 2,000 foot levels various stages of contact metamorphism

are shown. Geologically, these deep-lying limestones underneath the Weber quartzite are to be correlated with those which outcrop on the south, along Snake Creek, and are probably of Madison (Mississippian) age. The metamorphosed limestones cut by the 1,500-foot level drain tunnel belong to this formation. Those cut farther east overlying the Weber quartzite belong to the Park City formation and those still farther east to the Thaynes formation.

The intrusive rocks that have been cut by the workings of this mine are diorite porphyry. Specimens from some of the lower levels may more exactly be called quartz diorite porphyry with a monzonitic tendency. On the levels near the surface and adjacent to fissures, where alteration and decomposition have been active, the structure characteristic of the porphyries throughout the camp may be observed. In the fresh rock on the lower levels (1,500 to 2,000 foot), however, the feldspars have not been so decomposed as to stand out and the rock appears so evenly granular as to suggest that it is distinct from the porphyries. Microscopic, chemical, and comparative study tend to show, however, that the intrusive rocks cut on the Ontario property, though exhibiting certain local variations as in content of silica or in the form of quartz and of orthoclase, are the same. The intrusive rocks occur most commonly in the form of dikes from 1 to 100 feet in width, locally as sills, and in the deep eastern part of the mine as more massive, stocklike bodies. They have been cut in three parts of the ground explored. The most numerous and most extensive group lies in the western part of this property, adjoining the Daly. The largest single mass in the mine has been found in the eastern and deepest part, and a third group of intrusives occurs between these two on the 1,500-foot level west of the No. 3 shaft; also on the 1,700-foot and the 2,000-foot at the No. 3 shaft. In general these bodies are dikes which lie mainly in the footwall of the lode and trend northwest and southeast.

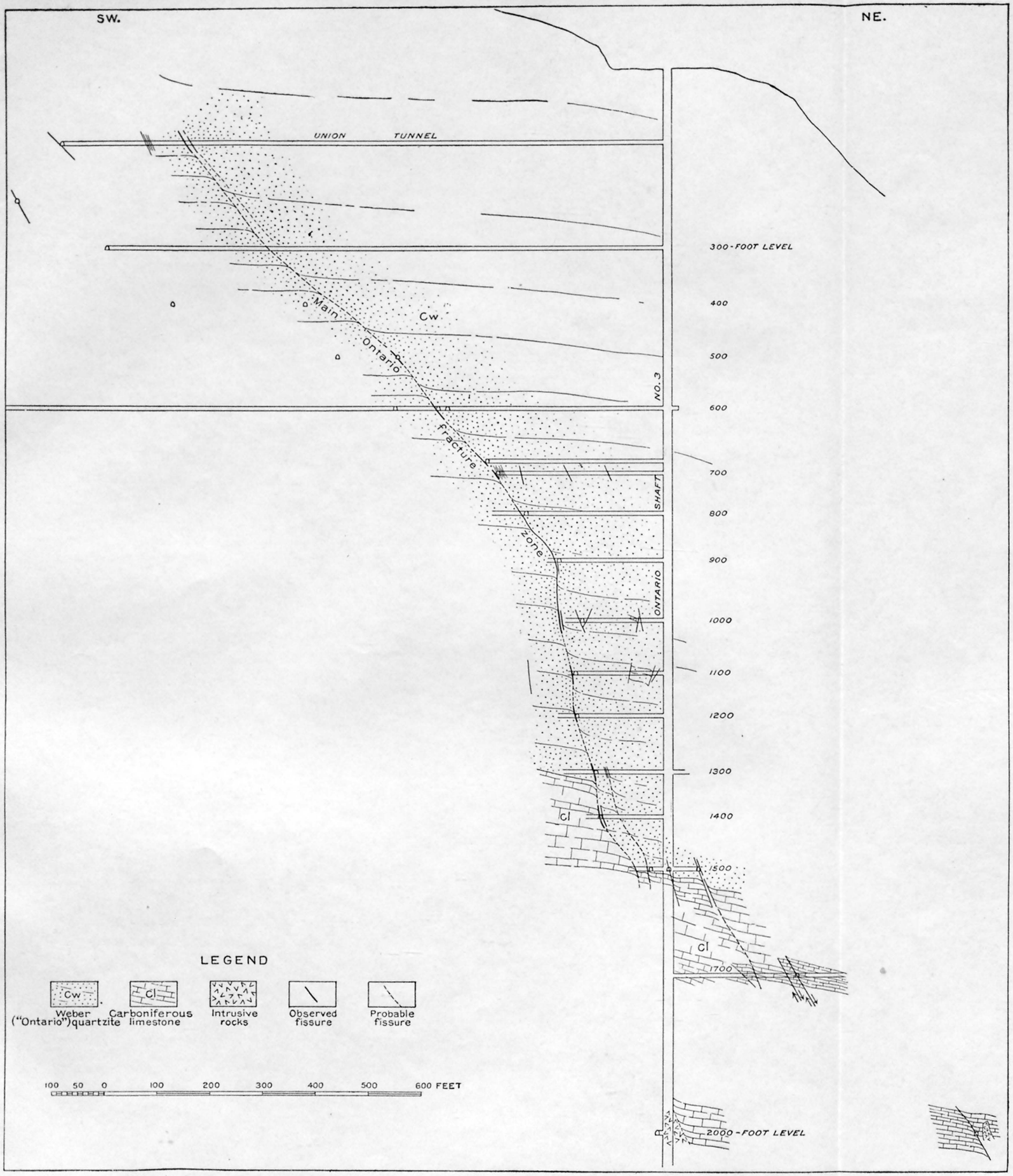
The western group is seen on the 600-foot level to consist of a number of northwest-southeast dikes from 10 to 200 feet wide and some irregular intrusives, which intersect in a complex manner the ground traversed by the two spur veins. The largest and best-known single body is a 35-foot dike, crossed 500 feet south of the work drift by the long crosscut running south, where it dips 75° N., and cut on its westward strike by spur 1, the work drift, and spur 2 about 1,500 feet west of the south crosscut. The great stocklike body in the vicinity of the No. 2 shaft on the 1,500-foot level, which is roughly 600 feet across, is identical in lithologic character with the masses opened on the 1,700 and 2,000 foot levels near the No. 3 shaft; also with the extensive body encountered immediately to the south, in the lower part of the Wabash mine.

The relations of these intrusives to the country rock vary. In some places the contacts are frozen, in others distinct slickensided planes bound the dikes, and in the vicinity of the larger masses, such as that near the No. 2 shaft, the limestones are as a rule highly metamorphosed. These several features are considered under separate heads.

The intrusives are older than the strong lode fissures and the period of mineralization. No intrusive was found of later date than the ore.

Structure and deformation of country rock.—The general structure of this composite country rock is simple, but the details of structure and the deformation which produced it are not only complex but in some instances are beyond exact determination. The main north-northeast axis of the Park City anticline passes through Ontario ground, following roughly the course of Ontario Canyon. Thus the beds on the east—for example, those just east of No. 4 shaft—dip to the northeast and east, and those on the west to the northwest and west. The prevailing dip of the sediments in the ground opened by mine workings, however, is toward the northwest. Local departures in the form of broad rolls and more restricted crumples also occur. Intrusives were observed to have produced local deformation.

The principal deformation in Ontario ground consists of a system of large and persistent fissures which trend northeast and southwest and dip northwest, together with their associated faults. The number of fissures or fractures varies from place to place, more having been encountered in some parts of the ground than in others. The Ontario workings cut a strong, persistent fissure with two similar ones probably branching from it as spurs, and two other fissures of considerable size in the footwall country rock. The position, relative location, and



GEOLOGIC STRUCTURE SECTION THROUGH ONTARIO FRACTURE ZONE. SECTION THROUGH SHAFT NO. 3, SHOWING ONTARIO FISSURE AND WALLS.

course of these fissures, also the country rock traversed by them, are well shown on the 600-foot level as represented on Plate XXXI (in pocket). The Ontario fissure is a strong, remarkably persistent fracture, from 1 to 100 feet wide, and extends more than 3,000 feet along its strike and more than 2,700 feet on its dip. Its strike varies from nearly east and west in the eastern part of the mine to N. 50° E. west of the No. 3 shaft. The dip also varies greatly, passing from a moderate inclination in the upper part to a nearly vertical position on its next lower portion and then flattening out again in depth. Thus, in the vicinity of the No. 3 shaft the dip averages 47° from the surface to the 800-foot level; from the 800-foot to the 1,400-foot it averages 75°, although from the 900-foot to the 1,200-foot it is 85° (in places becoming vertical); from the 1,500-foot to the 2,000-foot level it is about 45°; finally, on the 2,000-foot level measurements show an average of 60°. (See Pl. XL.) The width of the fracture zone on the surface at the "discovery" (see Pl. XXXII, *A*, p. 120) is about 2½ feet; on the Union (100-foot) and 300-foot levels it is 3 to 4 feet; on the 1,500-foot about the same width, although at one point west of the No. 3 shaft the zone of crushed quartzite reaches a width of 100 feet; and on the 2,000 foot (bottom) level it is 6 feet or more in width.

The walls of this great fracture zone are distinct polished wavy surfaces. Between them the country rock is in places merely fissured but is more generally crushed into small bits of white sugary quartzite. The prevailing direction of movement on these walls as indicated by the well-preserved slickensides appears to have been nearly coincident with the dip, diverging slightly toward the southwest.

The displacement on the Ontario fissure was considerable. The offset just west of the No. 3 shaft as nearly as can be determined amounts to 230 feet. In determinations the datum used was the contact between the Weber quartzite and the underlying limestone, which in the footwall appeared to be at a depth of about 1,330 feet and in the hanging wall was found at a depth of 1,560 feet. There was no opportunity to compare the relative displacement along this fault. The continuation of the fault west beyond the reported cropping of the fissure near the Daly shaft, however, suggests strongly that the principal fault on the west side of Empire Canyon directly in the course of this fault is the Ontario. If this is true, it follows that the displacement decreases westward to nothing, reverses, and on the west side of Empire Canyon has passed into the opposite phase, inasmuch as at that point the north side of the fissure has been relatively raised more than 100 feet.

The fissures that branch from the main fault in the western part of Ontario ground and extend southwestward are also strong fracture zones along which brecciation, slickensiding, and faulting have occurred. The direction of offset on the faults is believed to be generally the same as on the main Ontario fissure. No opportunity was found, however, to determine the amount of this displacement.

The relation of these fissures to the main fissure has been differently viewed by successive investigators. It may be most fittingly considered in connection with the occurrence of the ore. One view is that the so-called spurs are in reality northeast-southwest fissures, which existed before the Ontario fissure, and were cut and faulted by this great break. These are the only fissures observed that might have antedated the Ontario fissure, and the evidence for their earlier date is negative and inconclusive.

Faults later than the Ontario were found, though in Ontario ground they seemed very rare. Their scarcity accounts in large measure for the conditions that permitted following this lode without a break from the surface to the lowest levels and along the strike as far as the workings have gone. Three instances of this type of deformation may be described.

The most clearly shown example of faulting in the Ontario vein was seen on the 600, 900, 1,000, 1,100, 1,200, and 1,400 foot levels. About 1,000 feet west of the No. 3 shaft the main fissure is clearly offset along a transverse northwest plane. On the 1,100-foot level, where it shows most distinctly, this offset is seen to amount to about 35 feet northward on the west side. The plane here trends N. 70°–75° W. and dips 78°–80° NE., and its slickensides are inclined 75° W.

Another and more widely known line of deformation is a northwest-southeast sheet of breccia in the western part of the mine, known as the Dislocating fissure. This was traced by O. A. Palmer, consulting engineer of the Ontario Co., in the course of development from level to level and also along its strike. (See plate in the annual report of the Ontario Silver Mining Co. for 1898.) The best opportunity to observe this fissure was found on the 600-foot level, where it is cut by the long crosscut south of drain No. 0 and spur No. 1. On the east wall of the crosscut it appears as a zone of highly crushed and shattered quartzite about 20 feet in width traversed by numerous fracture planes. One plane, which was particularly well defined, trended about east and west (N. 85° E.), dipped 75° S., and showed slickensides pitching 45° E. (See fig. 17.) Again, at the Y on spur No. 1, a zone of breccia was encountered in the line of this dislocation. The spur appears to be offset along this zone about 60° to the west on the north side, but the zone and the adjacent vein were not sufficiently opened to prove this point. Reference to the mine map shows similar development at this point on levels above and below. To the northwest, where it is crossed by the work tunnel, this zone of dislocation is marked by brecciation in the quartzite and beyond, at the western border of this property, by a strong east-west fissure dipping 60° S. This northwest-southeast fracture has been regarded by some as a continuation of the Massachusetts fault. Comparison of the position of these faults, however, as plotted on an accurate composite mine map of the district, reveals the fact that the Dislocating fissure lies many hundred feet too far south to be continuous with the Massachusetts fault, and it is to be recalled, furthermore, that the amount of offset, though in the same phase, is almost a thousand times greater in the Massachusetts fault than in the other; accordingly it is clear that they are not the same.

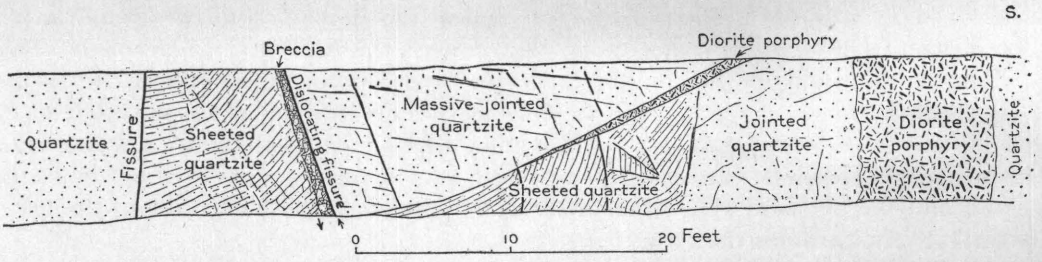


FIGURE 17.—Dislocating fissure and adjacent deformation, 600-foot level, south crosscut, Ontario mine.

A deformation known as the "East fault" is reported to have interrupted the Ontario vein. As most of the eastern workings of the mine were abandoned and inaccessible at the time of visit, much of the information on this fault has necessarily been gained from reports, and from maps showing mine workings. The main facts are that the Ontario lode was followed eastward to a strong fracture zone and that the continuation of the lode beyond has never, so far as known, been found. Those directing the work state that a great north-south fault was encountered at this point and that it was found on successively deeper levels. It was most extensively explored on the 600-foot level.

The observations of the writer were confined to the 1,500-foot level and the surface. On the 1,500-foot level, about 340 feet west from the No. 2 shaft, the country rock of porphyry and overlying metamorphosed limestone is intensely shattered and crushed. In the marble two slip planes are noticeably prominent—one N. 10° E., dipping 45° NW., with vertical slickensides, the other N. 15° E., dipping 70°, also with vertical slickensides. Immediately east the rock is highly crushed for about 100 feet. Again, the north crosscut from the No. 2 shaft passes through a corresponding zone of crushing for about 40 or 50 feet, which lies in the trend of the other fracture zone and is apparently its extension. Workings lie on its course to the northeast. The mine map shows workings on the 100, 1,200, 1,500, and 1,600 foot levels whose position and course suggest that they were run on this fracture zone, and it is reported that this was done. According to these data, the fracture trended north-northeast and dipped

westward at an average angle of 45°, flattening and bulging slightly near the 1,200-foot level. On the surface, where a fracture in that position with that dip would appear, are strongly brecciated ferruginous quartzite zones trending northeast. These are best seen on the slope overlooking Lake Flat from the east, also at several points farther north. Little doubt exists, therefore, of the presence of a strong fault at the east side of the Ontario mine which has truncated the Ontario lode.

The chief uncertainty is with regard to the direction and amount of faulting. Prospecting both north and south has been carried on for many years in the hope of discovering the continuation of the lode, but it has not yet been identified with certainty. The broad geologic features suggest a southward movement of the east side, but evidence demonstrating this could not be found.

Croppings of ore bodies.—The Ontario lode has been uncovered and opened at the surface on the east slope of Ontario Canyon from the top near the Parleys Park shaft to the bottom in the rear of No. 2 Ontario shaft, a distance of about 1,100 feet. A cropping which is also considered to be of this lode appears just west of the Daly boarding house. Between these points it has not been traced on the surface.

In the vicinity of the "discovery" (Pl. XXXII, *A*, p. 120) the fissure traverses massive quartzite and shows distinct walls. The contents have of course been removed and the shattered wall rock reveals comparatively little indication of the extensive mineralization below. It shows no metallic matter, but is stained black, green, and brown. The black coating is manganese oxide. The green is malachite and occurs both in radiate groups of acicular crystals and in massive form. Some of it appears to overlie or coat the manganese oxide and, locally, the brown material that stains the rock coats both. The quartzite itself has been turned into massive white quartz and chalcedonic quartz, in places pitted and honeycombed.

Form of ore bodies.—The form of the ore bodies in this property is generally tabular—that is, the ore lies within a great fissure and thus has its greatest extent in the directions of the strike and dip of the fissure and is comparatively thin. The details of this general form could not be satisfactorily observed at the time of visit, as the filling had been stoped out. Earlier observers have stated that the ore formed a single great shoot, which outcropped for a few hundred feet, pitched southwestward, thus descending beneath the outcrops of the fissure, and extended westward in depth. Division into distinct shoots could not be determined. The stope map published by the company in 1901 showed stoping from the surface in the vicinity of the "discovery" and Last Chance tunnel down to the 1,500-foot level; westward between the 500 and 800 foot levels beyond the No. 3 shaft; in a triangular area between the 300 and 1,100 foot a few hundred feet beyond; also a few hundred feet still farther west beyond the 200 and 900 foot levels. In so far as may be judged from this stope map the best ore in the tabular ore body would appear to have been roughly localized in three shoots, which pitched steeply southwestward.

In 1880 [1] it was pointed out that—

> In the hill east of the shafts the ore came within 15 feet of the surface for 150 feet in length. In other places ore which could be profitably extracted did not come within 100 feet of the surface, from which depth the ore body extended from 900 to 1,500 feet in length along the vein. Between the 100 and 400 foot levels there was a contraction of the vein for 100 to 200 feet in length. In the lower levels there were enlargements of the vein, three chimneys as a rule being found upon a level. These were from 100 to 300 feet apart and 6 to 8 feet wide and 50 feet long.

The following year [2] it was stated in a report made by experts to the company that—

> The ore has been deposited in the fissure in a continuous sheet extending from the surface downward as far as the explorations have penetrated, forming a well-defined "ore shoot." At the surface this shoot had a length of only about 500 feet. As this ore shoot was followed in depth it increased in length until at present on the 600-foot level it has attained a length of 1,500 feet and the west face is still in good ore. Not only has the shoot increased in length as it has been explored in depth but there has also been a gradual increase in the width of milling ore, which in the upper levels averaged 1 to 1½ feet, while on the fifth and sixth levels it is at least 2½ feet wide and for considerable distances occupies the whole breadth of the fissure.

[1] Huntley, D. B., Tenth Census, vol. 13, p. 439.
[2] Extract from a report by William Ashburner and Walter P. Jenney: Eng. and Min. Jour., vol. 31, May 28, 1881.

It appears, then, that the ore body was in the general form of a sheet, which was constricted in the direction of dip so as to separate three thicker portions, "chimneys" or shoots.

The form of the body varies greatly in the direction of its thickness. At certain points the ore body is a single pay streak a foot or more in width that fills the entire fissure from wall to wall. At others the streak occupies only a part of the fractured zone, as seen 90 feet above the 1,500-foot level west of the shaft, or is one of several layers which run through the filling of breccia, as seen in a stope on the 1,500-foot level west of the shaft. Again the ore is scattered through the breccia in bunches, as on the 1,100-foot level from 250 to 300 feet west of the shaft crosscut, on the 1,500-foot level in the Big stope, and on the 2,000-foot level east.

Strike and dip.—The ore bodies strike in a general east-west direction and dip toward the north, following the fissures that inclose them. Toward the west their strike turns more and more to the south, giving them the general shape of a bow or crescent opening southward. The extreme limits of this variation are in the eastern part of the mine, where the course is about east and west, and just west of the No. 3 shaft, where it is about N. 50° E. The average strike of the Ontario lode is about N. 60° E. A few actual measurements will indicate these general and local variations on the following levels: Union, 100-foot, spur Daly line, N. 55° E.; midway between Daly and No. 3 shaft, N. 60° E.; 300-foot, 1,400 feet east of Daly line, N. 62° E.; Daly line, due east and west; 600-foot, 400 feet west of crosscut to No. 3 shaft, N. 80° E.; 90 feet above 1,500-foot level, 300 feet west of shaft crosscut, N. 45° E. The fractures in the foot of the main fissure varied from N. 40° E. to east-west; on the 2,000-foot level 500 feet east of crosscut shaft, N. 65° E.; 200 feet east of crosscut, N. 60° E.

The dip of the ore bodies, likewise following that of the inclosing walls, averages about 50° but varies from 40° to 89°. (See p. 141.) It is steep near the surface, flattens below, then grows steep again from the 900-foot to the 1,300-foot level, and gradually flattens once more still farther down. The course followed by the fissure in its descent comprises two reverse curves, simulating the form of an ox yoke (Pl. XL, p. 140). Actual measurements are, on the 100-foot level at shaft crosscut, 46°; on the 300-foot at Daly line, 56°; 1,400 feet east of Daly line, 65°; at spur 1 on Daly line, 60° and 67°; on the 600-foot just west of crosscut to No. 3 shaft, 52° to 55°; on the 1,500-foot (80 feet above) 300 feet west of crosscut to shaft, 75°; on the 1,700-foot 500 feet west of shaft, 50°, and 1,000 feet west of shaft crosscut, 65°; and on the 2,000-foot 500 feet east of shaft crosscut, 60°, and 200 feet east of crosscut, 65°.

The general strike of the ore-bearing fissure is well indicated by the map of workings on the 600-foot level (Pl. XXXI, in pocket), and the general and broader variations in the dip are brought out by the cross section of the fissure in the vicinity of No. 3 shaft (Pl. XL, p. 140).

Walls.—The walls of the Ontario ore bodies are sharply defined. For example, on the 1,100-foot level 250 feet west of the shaft 15 to 20 feet of quartzite breccia is inclosed by well-defined walls both of which are highly polished. In short, the walls are clean and sharp throughout the mine and, as noted by Ashburner and Jenney [1] in 1881, the ore "cleaves readily from them."

Some difference may be noted between walls in igneous rock and those in quartzite, the latter being as a rule more regular and even. No differences along the strike were observed, nor were the walls found any less distinct at a depth of 2,000 feet than at 100 feet.

General character of ore.—The Ontario ore is a silver-lead milling ore carrying accessory zinc and iron in a siliceous gangue. It was oxidized to carbonate in the upper levels and passed into sulphide ore in depth. The vein carried rich pay streaks. These were so inclosed in low-grade material that the entire contents had to be mined, and this averaged medium grade. Despite high costs, the large quantity of ore and the thorough mining methods employed have made possible large profits. The ore of the lower levels, from 1,500 to 2,000 feet, which now constitutes the principal reserve, is somewhat lower in grade and more zincky than the ore above, but under modern methods of milling it yields a fair saving.

[1] Op. cit., p. 365.

Mineralogic character of ore.—The Ontario ore mined at present is largely an intergrowth of galena, pyrite, and blende in a quartz gangue. Silver is present and lies in the galena and to a greater extent in the pyrite. Hornsilver was common, it is stated, in the upper part of the vein. Tetrahedrite and chalcopyrite are here and there associated in small quantities. A little copper was found in the form of bornite, chalcocite, and the black oxide, and in the upper levels azurite, malachite, and chrysocolla. The sulphate and carbonate of lead (anglesite and cerusite) also occur within the zone of surface alteration. Pyrrhotite, magnetite, and hematite were found in small quantities. Locally, calcite, dolomite, and rhodonite appear in the gangue. Serpentine, garnet, and epidote are also present in the vicinity of certain intrusive rocks.

Tenor of ore.—The Ontario ore in 1904 contained on an average silver 18 per cent, lead 2.125 per cent, copper 0.286 per cent, gold 0.02125 ounces to the ton, zinc 6 per cent, and iron 3.77 per cent. From these a concentrate was made which averaged silver 84.91 ounces to the ton, lead 13.53 per cent, copper 1.29 per cent, gold 0.07 ounce to the ton, zinc 16.53 per cent, and iron 12.35 per cent. Of the silver 73 per cent has been saved, and it is believed that an average saving of 70 per cent can be maintained; of the lead, 93 per cent has been saved, and 90 per cent is regarded as a possible average.

In general the ore from about the 600-foot to the 800-foot level was highest in value. Thus in 1880 the ore from these upper and better levels was reported to "assay from $40 to $700, the battery samples averaging about $130."[1]

DALY MINE.

SITUATION AND HISTORY.

The Daly mine is situated 1½ miles south of Park City, on the east side of Empire Canyon. It adjoins the Ontario on the west.

The 24 claims composing this property are located on the westward extension of the Ontario lode. When the Ontario property began to show its great value these claims were taken up by J. J. Daly. In February, 1885, the Daly Mining Co. was formed. The organization of the Daly and Ontario companies has been in part identical, and the two companies have always conducted their operations in conjunction.

The early prospecting for the Ontario lode on this ground was done by means of numerous tunnels. Upon the organization of the Daly Co., however, a shaft was sunk 800 feet, and connection was made with the Ontario workings. Some further exploration demonstrated that the Ontario vein extended into the Daly ground, and after $200,000 had been expended on the property without any earnings the mine began to ship regularly on January 1, 1886. It maintained its output, rivaling at one time its famous neighbor, until November, 1897, when the company ceased to operate this property actively. Since that date lessees have not only shipped considerable excellent ore from the main vein but by systematic prospecting have found new veins. In the last few years, encouraged by the important development of rich ore bodies in adjacent ground, the company has prospected the western part of this property through the Mazeppa shaft, where some rich silver ore was found, and later through the cross-cutting Federal tunnel.

The ores, being of the same character as the Ontario ores, have received similar treatment. They were reduced by the Russell lixiviation process at the Marsac mill, and the silver was then extracted and treated in a Stetefeldt refinery.

[1] Huntley, D. B., Tenth Census, vol. 13, p. 439.

PRODUCTION.

The total output from the mine reported up to the end of 1904 is $9,450,355, from which dividends have been paid amounting to $2,887,500. The amounts year by year are given in the following table:

Production and dividends of the Daly mine.[a]

Year.	Tons.	Silver, ounces.	Gold, ounces.	Sold for—	Dividends.
To Dec. 31, 1886	20,562	1,277,539.58	1,526.60	$1,143,847.38	.....
1887	22,618	1,033,091.50	782.99	967,113.16	$375,000.00
1888	25,524	1,135,527.06	968.93	1,047,859.59	487,500.00
1889	28,856	1,267,661.41	1,414.39	1,113,045.65	450,000.00
1890	23,146	817,011.32	704.24	834,818.91	450,000.00
1891	29,948	1,272,170.32	1,271.37	1,166,614.43	450,000.00
1892	27,370	1,192,867.53	1,288.30	997,762.40	450,000.00
1893	26,568	1,025,134.39	1,166.79	745,732.77	187,500.00
1894	22,183	749,623.23	767.96	481,866.34	.....
1895	22,900	582,342.42	67.01	389,911.71	.....
1896	20,327	514,166.86	229.65	348,209.15	37,500.00
1897	5,869	216,149.24	282.61	127,151.73	.....
1898	220	28,526.67	26.62	17,082.48	.....
1899	233	19,561.60	35.48	12,392.50	.....
1900	469	33,555.68	56.47	20,719.82	.....
1901	1,175	62,175.89	69.51	24,405.21	.....
1902	114	9,866.85	11.14	4,973.55	.....
1903	82	4,768.78	5.45	2,605.77	.....
1904	105	7,301.43	9.10	4,243.34	.....
	278,269	11,249,041.76	10,684.61	9,450,355.89	2,887,500.00

[a] From report of the Daly Mining Co. from Jan. 1, 1896, to Jan. 1, 1897. Figures for the years 1897 to 1904 were kindly furnished by Mr. C. L. Rood, superintendent of the company.

PLANT.

During the active period of this property it was thoroughly equipped with the most improved hoisting plants at both shafts, had an excellent boarding and bunk house, and used jointly with the Ontario mine the work and drain tunnel and extensive workshops. The Marsac mill, which was owned by this company in 1887, was then equipped with steam power, double engines, two revolving driers, 30 stamps for crushing ores, rolls for crushing salt, a Stetefeldt furnace of 60-ton capacity for chlorination, 16 pans for amalgamation, 8 settlers, retorts, melting furnaces, and complete electric-light and fire-extinguishing plants.

Since the mine was closed and practically passed into the hands of the Ontario Co., some of its equipment has been utilized at other points. The Marsac mill in the summer of 1904 was dismantled and the building leveled to make space for house lots. This company is jointly interested with the Ontario and Daly West companies in the White Pine waterworks, whose source of supply is the small lakes at the head of Bonanza Flat. Valuable coal mines at Coalville, on the Union Pacific Railway 35 miles north, are also jointly held by these companies.

DEVELOPMENT.

The Daly property has been developed through two shafts, Nos. 1 and 2, to a depth of 1,000 and 1,200 feet, respectively, and by levels turned at 100-foot intervals, also by two long crosscut tunnels, the Central and Federal. The main development comprises the 200 to 1,000 foot levels which have been run from the No. 1 shaft along the Daly vein from the Ontario line westward to the Daly West. The collar of the Daly shaft is 200 feet higher than that of the Ontario No. 3 shaft. Accordingly, the corresponding Daly levels are deeper than the Ontario levels by that amount. Thus the Daly 800, the work-tunnel level, is the Ontario 600, and the Daly 1,200, its lowest level, becomes in the Ontario the 1,000-foot level. Drifts on the Ontario vein on the 700 to 900 foot levels and on others southward on the 800 and 1,000 foot levels are also reached through this shaft. The three-compartment No. 2 shaft, which was sunk late in the history of this property in Ontario ground about 200 feet east of the Ontario-Daly line, affords access to workings on the 500-foot and the 1,000 to 1,200 foot levels. The Federal tunnel from its mouth, on the west side of Empire Canyon opposite Daly No. 1 shaft, extends in a general southerly direction for about 1,500 feet, and the Central tunnel, entering the slope immediately south of the No. 1 shaft, extends southeastward for about the same distance. The most extensive single level is the 800-foot.

The Daly property so closely resembles the Ontario that it may be best described by comparison with that. Furthermore, the fact that it was not being operated at the time of visit and only certain levels which could be entered through adjacent properties were accessible rendered a complete detailed study impracticable. Therefore, only a general statement will be given.

Character of country rock.—In general the country rock on this property is like that on the Ontario-Weber quartzite, limestone, and igneous rock. In addition, however, the property includes in its western part the lower members of the Park City formation, and within the Weber quartzite appear a number of apparently local intercalated carbonaceous limestone members or lentils. Thus the No. 1 shaft is stated to have been sunk in this limestone to a depth of 300 feet, below which it continued in quartzite with calcareous intercalations. The upper part of the No. 2 shaft is also reported to have been in limestone. In the rear of No. 1 shaft the writer found large blocks of limestone bearing an abundant fauna which has been identified as that of the Park City formation. North of the No. 2 shaft, in a gully east of the spur leading to the Daly-Judge tunnel, numerous prospect tunnels have revealed the gray carbonaceous limestone characteristic of the lower part of the Park City formation. It is also well exposed in the Daly-Judge tunnel northward to the Massachusetts fault near its mouth. The intercalated calcareous members, as observed on the 800-foot level, are thin gray limestones and impure black shaly carbonaceous limestones. They are well shown on this level in the long crosscut from the No. 1 shaft southward.

The igneous rocks, as also mapped on this level (Pl. XXXI, in pocket), are dikelike masses, for the most part narrow and regular. They range from a foot to over 200 feet in width, but probably average about 20 feet. Their prevailing trend is northwest and southeast, but in several places they run about east and west. These porphyry dikes have been cut on the east side of the property, adjoining the Ontario ground, and near and due north of No. 1 shaft. Most of them are clearly the continuations of bodies which were followed in the Ontario ground for many hundred feet.

Structure and deformation of country rock.—The structure of this composite country rock is simple. In general the sediments dip toward the northwest at about 35°, but local crumpling and variations in this prevailing dip occur. Transecting the sediments and porphyry alike is the great northeast-southwest Ontario fissure zone. Within the limits of this property the zone embraces six major fissures, a greater number than have been opened in any other property on this zone. They dip northward, except a strong one which on the 800-foot level is about 800 feet south of the Daly No. 1 shaft; this dips 70°–85° S. The ground intervening between these master fissures is complexly broken by a large number of minor fissures and small slip planes. These are approximately parallel and strike northeast and southwest—some of them more northerly than the major fissures.

Ore bodies.—No gossan has been found on this property. Two outcrops have been accepted as the surface indications of the two most important lodes. The outcrop of the Ontario vein is commonly considered to be represented in a pink quartzite bowlder 100 feet southeast of the southeast corner of the Daly boarding house and by a similar ledge just west of the boarding house, which shows bands of white, gray, and brown chert in altered quartzites or siliceous limestone. These occupy the proper position for the outcrop of this vein and the ledge may be a part of its wall. The apex of the Daly vein is commonly regarded as being at a point about 750 feet south of the Daly No. 2 shaft and 700 feet east of the Daly No. 1 shaft. An abandoned inclined shaft at this point is stated to be the upper end of a raise on the Daly vein from the 800-foot level.

The ore bodies lie exclusively within fissures. In their general features they are stated to have been like those occurring in the Ontario fissure within the Ontario property—tabular bodies with lenticular enlargements. A somewhat unusual form of vein was described in the annual report of the Daly Co. for 1896–97. It appears in a cross section of the Daly vein immediately south of the No. 1 shaft and is a fracture zone dipping 20°–25° N., which is wide in its upper portion (above the 500-foot level), reaching a maximum width at the 200-foot level of 140 feet

from wall to wall, and decreases in depth to a constant width of 20 to 30 feet. The enlargement of the upper portion is said to be partly occupied by masses of "broken quartzite," which is penetrated by fingers and stringers of ore. The narrower lower part of the lode is said to have been stoped out to a width of 40 feet at a depth of 700 feet.

So far as shown by present development the shoots reach their largest dimensions above the 800-foot level and both of the paying lodes decrease in size and in contents below that level. There remains a possibility, of course, that these lodes again enlarge and embrace other shoots at greater depths, though on the bottom level both fissures appear quite barren.

The ore-bearing fissures in this property pass westward from the Ontario in a zone measuring, on the 800-foot level from the most northern to the most southern vein known, 2,800 feet in width. The four northernmost are from 600 to 1,000 feet apart and the two southernmost follow at intervals of about 100 and 600 feet. They are known from north to south as the North vein, which lies more than 1,600 feet north of the No. 1 shaft; the Ontario vein, 560 feet north of this shaft on the 800-foot level; the Daly vein (spur No. 1 from the Ontario vein on Ontario ground), 70 feet south of the shaft; the South vein, 735 feet south of the shaft; the Middle vein, 840 feet south; and the Dixie vein, about 1,480 feet south.

These six veins have been extensively opened and a large number of smaller ones have been prospected. The North vein on the 1,200-foot level consists of a strongly brecciated zone from 1 to 5 feet wide in ferruginous quartzite and porphyry. At the point observed it did not appear to carry ore, though on assay good values are said to have been revealed. The Ontario vein, opened on the 700, 800, and 900 foot levels from the No. 1 shaft and on the 1,100 and 1,200 foot levels from the No. 2 shaft, has failed to afford ore bodies of commercial value. On the 800 and 1,200 foot levels it appears as a strong fracture zone but is practically barren.

The Daly vein has yielded over 3,000,000 tons of ore, or the bulk of the output from this property. This was taken from above the 900-feet level. On the 1,100 and 1,200 foot levels the vein has been entered from the No. 2 shaft but only slightly explored. The points examined on the 1,200-foot level were evidently below and outside of the great ore shoot, for it there appeared to be a strong though barren fissure. The South vein at the points cut on the 800 and 1,000 foot levels shows from 1 to 5 feet of brecciated quartzite stained with iron manganese and copper and includes good ore between quartzite walls. On this level the vein has been followed westward to the Daly West line and there found to be 18 inches wide and to present a promising face. The spur from this vein, known as the Middle vein, has been opened on the 800-foot level from a point 300 feet west of the Ontario line to the Daly West line and found to yield some good ore, but it is interrupted on the west by complex deformation. The Dixie vein, lying next south of the Middle vein, has been opened at two points on the 800-foot level from the Ontario line westward for several hundred feet, also on the 1,200-foot level. At all these places it has yielded pay ore and looks promising. It seems probable that further exploration of the South vein toward the east would show that the Dixie branches from it in the vicinity of the Ontario line.

Strike and dip.—These major fissure and fracture zones traverse the Daly ground in a general west-southwest direction. They dip, with rare exceptions, northward at angles from 70° to nearly vertical. The South vein and its spur, the Middle vein, however, dip 70°–85° SW.

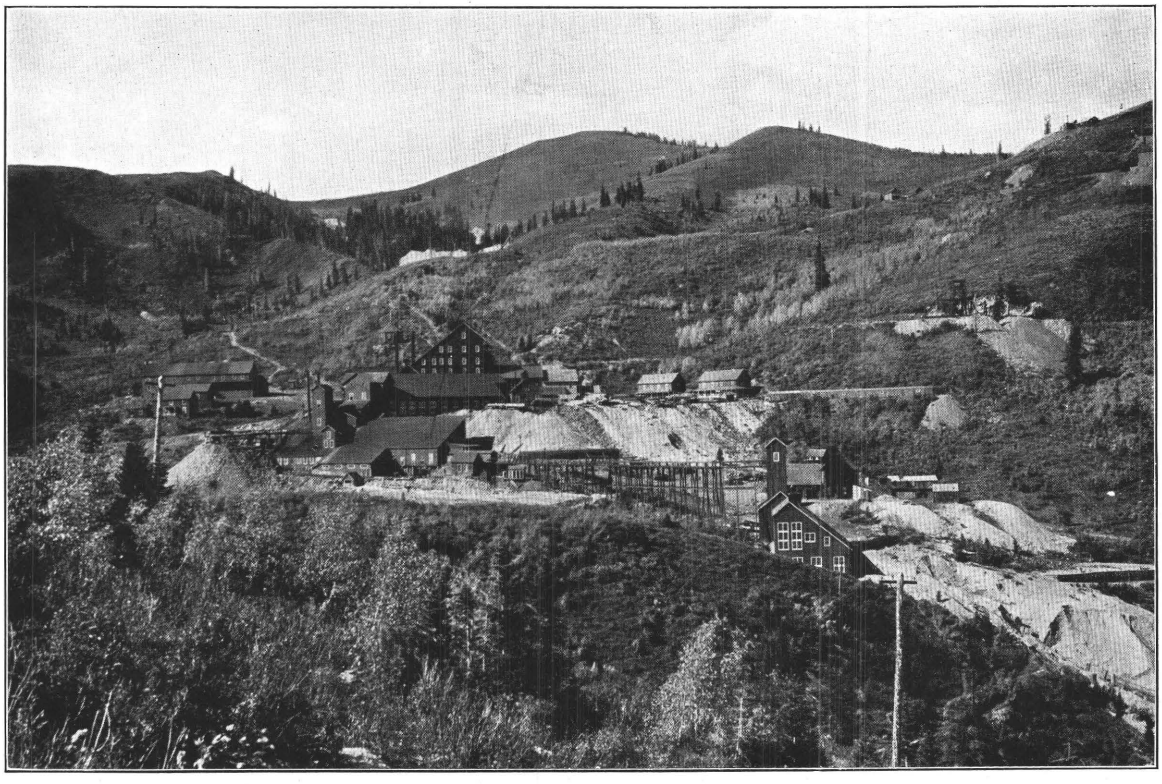
Character and tenor of ore.—The character of the ore yielded by these veins could be observed at only a few points. It is understood to have been in all essentials like the Ontario ore already described—a silver-lead ore carrying copper and gold and some zinc in a quartz gangue. Most of it was of milling grade, but some is reported to have carried a high content of silver.

DALY WEST MINE.

SITUATION AND HISTORY.

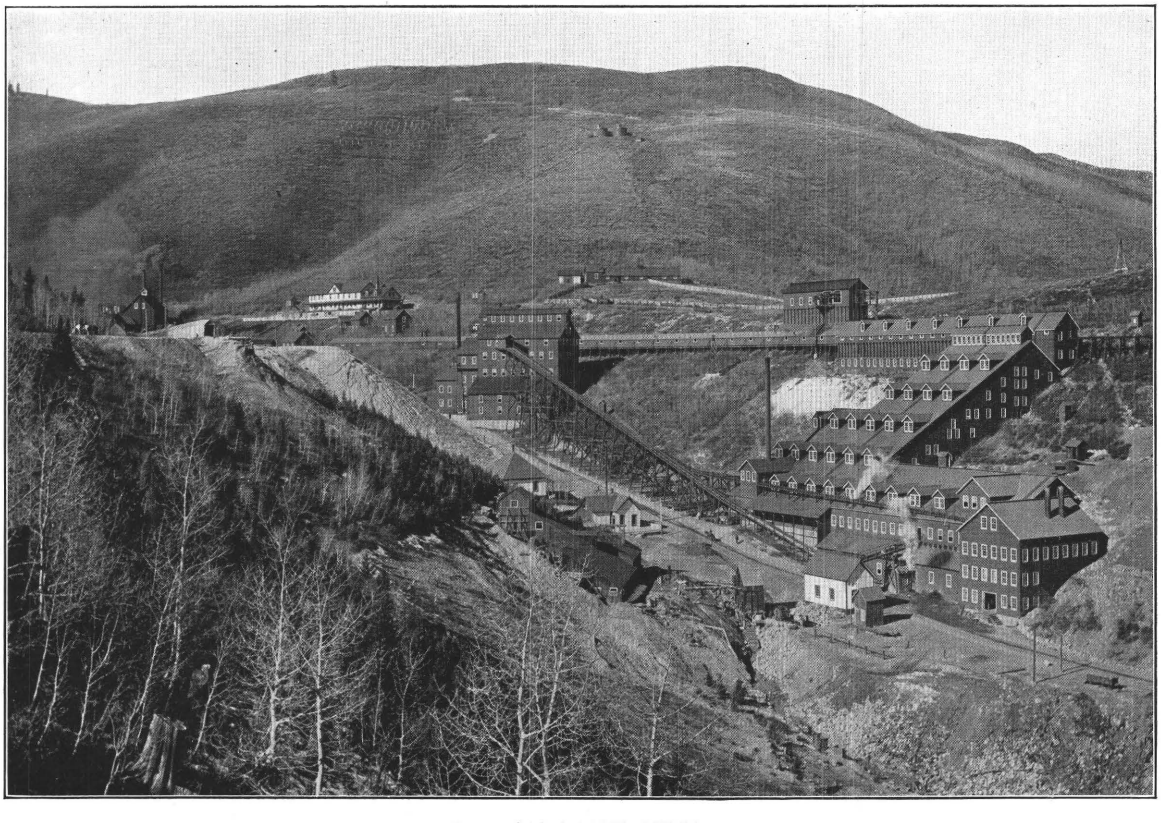
The Daly West mine is situated 2 miles south-southwest of Park City, near the head of Empire Canyon (Pl. XLI, *B*).

The indications afforded by the development of the Daly mine that the great Ontario lode extended westward beyond the limits of the Daly property led to active prospecting and locating



A. SILVER KING MINE.

Shaft and office at left, sampler in middle, mill at right. Looking southwest.



B. DALY WEST MINE.

Office, shaft, and mill in middle ground; Daly-Judge shaft in background at center, and Diamond-Nemrod shaft at right. Looking southwest.

during the middle eighties around the head of Empire Canyon. Since the early days ground at the extreme head of the canyon has been worked, and at this time areas which might embrace the westward extension of this lode were taken up. "The original holdings of the Daly West property embraced 40 patented lode claims, an undivided half being owned by Messrs. J. B. Haggin, George Hearst, R. C. Chambers, et al.; the other half by John J. Daly." [1]

After some exploration the owners began systematic development of their property in the summer of 1891. At this date, when the shaft had reached a depth of 300 feet, new hoisting works were erected and machinery suitable for sinking to a depth of 1,500 feet was installed. In June, 1892, the mine was closed owing to the low price of silver and lead, but, in spite of this interruption, by December of that year the shaft had reached a depth of 1,255 feet and was connected with the west drift from the Daly mine. "In October, 1893, Mr. Daly incorporated his one-half as the Daly West Mining Co., with $1,500,000 capitalization in $20 shares," [1] under the laws of Utah. Soon after the other half was acquired by the Ivanhoe Mining Co., of California.

Owing to the low price of silver, mining operations were suspended during the later part of the year 1893. Rich ore was found in the summer of 1894 and a period of extensive development and active mining followed. Throughout the following year the output increased largely. In August, 1895, the concentration mill was constructed and the Ontario-Daly-Daly West pipe line, leading an abundant supply of excellent water from the lakes at the head of Bonanza Flat, was laid. New hoisting works were erected in November, 1896, and early in the following year another large body of ore was opened.

The mine then lay idle until March, 1898, when active operations were resumed. In December differences that had arisen between the two owning companies—the Daly West and the Ivanhoe—were adjusted and early in 1899 the companies were consolidated under the name Daly West Mining Co. In June of the same year this company alleged that the Anchor Co. had taken out ore from Daly West ground and filed suit for $200,000 against the alleged offenders. A compromise was effected and the Anchor Co. paid the Daly West $12,500.

The next important event in the growth of this property was connected with the Quincy mine, which adjoins the Daly West on the southeast. The Quincy passed through a unique and most successful career. When interest arose in this section of the camp eight claims were staked and in the earliest stage of their development they were leased and bonded, under the name Putnam Mining Co., to Col. W. M. Ferry. Soon after six other persons took a two-thirds interest, and in 1898 or 1899 the owners incorporated as the Quincy Mining Co. Hoisting works were erected and active development was begun. At a depth of 110 feet ore was struck in the shaft and on following this down a large shoot of lead-silver carbonate ore of high grade was opened. Shipments were begun and rapidly increased so that by the close of the first shipping year, 1901, the output had reached $725,000. Thus in practically one year this mine took second rank among the producers of the camp and by June, 1902, it had assumed the lead.

Before development had proceeded for half a year the probability of a connection between the ore bodies of the Quincy and Daly West ground became evident. In the spring of 1902 the Daly West Co. brought suit against the Quincy for ore alleged to have been taken by the new company beyond its end line in Daly West ground. Thereupon the Quincy brought counter suit claiming that the ore mined by the Daly West was under the Quincy apex. At this time members of the Daly West Co. secured a large interest in the Little Bell property, which adjoins the Quincy on the southeast. The issue was adjusted before reaching trial by an exchange of 30,000 shares in the Daly West Co. (provided by increasing its capitalization from 150,000 to 180,000 shares) for the entire Quincy property on the basis of five shares of Quincy stock for one of Daly West. The mine was operated as before the consolidation, yielding large quantities of high-grade ore, until September, 1904, when its plant was closed. It was worked afterward through the Daly West.

In July, 1902, an explosion in the powder magazine on the 1,200-foot level killed 38 persons—2 from the explosion and 36 from asphyxiation. The cause remains unknown.

[1] Ann. Rept. Daly West Mining Co. for 1900, p. 5.

The Daly West property now comprises the original holdings of the Daly West and Ivanhoe companies, the Morgan group of 15 patented claims adjoining the main group on the north, the Dolberg group, the Quincy property adjoining the Daly West on the southeast, a control in the Little Bell lying immediately southeast of the Quincy, and a large share in the Weber Coal Co.

The extensive, complete, and highly efficient plant is the result of repeated enlargement and improvement. Underground there is a perfected system of lighting by electricity and of bell and flash signaling. The surface improvements include offices, boarding house for 400 men, bunk houses for men and officers, hoisting works, an 80-foot wooden gallows frame, a compressor plant, separate machine shops for mine and mill, a carpenter shop, and three concentrating mills. The equipment of the three mills and the mode of operating them are described under "Reduction" (pp. 30–31).

In general this property has been developed on an excellent system and is operated by business methods. Ore from the upper workings descends to the 900-foot level, whence the shipping ore, together with that from the 1,200, 1,400, and 1,500 foot levels, goes to the loading station on the 1,200-foot level. The milling ore is hoisted to the surface, is automatically dumped, and passes to the bins at the head of the mill. The concentrates are reloaded into cars and sent to the loading station on the 1,200-foot level. From that point trains are drawn by horses through the Daly West, Daly, and Ontario work tunnel, a distance of about 2½ miles, to the loading station at the mouth of the tunnel in Park City. Here the concentrates are weighed and shipped by rail to the American Smelting & Refining Co.'s smelter in Salt Lake Valley.

In addition to exploring the ore-bearing limestone for other bonanzas, it was proposed in 1904 to develop the great Daly West lode in depth and to work this on a greatly increased scale for milling ore. To this end an agreement was made with the Ontario and Daly mining companies to extend the deep Ontario drain tunnel to Daly West ground, as stated under "Ontario mine" (p. 138).

PRODUCTION.

This mine was opened with the definite object of working the westward extension of the Ontario-Daly lode. The lode was struck early and shipments were made almost from the start. The first dividend, 20 cents a share, amounting to $30,000, was paid in September, 1899. In January, 1900, the rate was increased to 25 cents, and it gradually rose until in September, 1903, it reached 65 cents a share, amounting to $117,000 a month, or $1,404,000 a year. At that time this mine was paying a larger dividend than any other mine in the district and was in fact one of the largest dividend payers among the lead-silver mines of the world. This monthly rate was maintained until May, 1904, when, owing to depletion of the reserves of first-class ore, it was decided to reduce the dividend to 40 cents a month, which was paid for the remainder of that year. Subsequently it was further reduced to 40 cents a quarter. The total product of this mine from 1893 to 1906, inclusive, sold for $11,203,420.22 and afforded in dividends $5,499,000. The record of the output and dividends, by years, is given in the following table:

Output and dividends of Daly West Mining Co.[a]

Year.	Copper.	Lead.	Gold.	Silver.	Sold for—	Dividends.
	Pounds.	*Tons.*	*Ounces.*	*Ounces.*		
Nov., 1893, to Dec. 31, 1898		3,312	656.56	649,843	$336,149.13	
1899	629,318	3,596	660.87	733,981	529,017.22	$120,000.00
1900	1,193,839	6,587	1,310.69	1,388,755	962,501.40	487,500.00
1901	1,326,448	7,793	1,606.72	1,755,454	1,113,229.28	607,500.00
1902	2,403,670	14,903	2,943.96	3,575,796	1,827,585.72	1,044,000.00
1903	3,160,824	17,372	3,195.28	4,382,222	2,382,357.39	1,332,000.00
1904	2,023,005	12,826	2,376.36	3,064,224	1,804,672.83	1,044,000.00
1905	1,225,731	8,386	1,396.85	1,798,628	1,234,458.71	432,000.00
	11,962,835	74,775	14,147.29	17,348,903	10,189,971.68	5,067,000.00

[a] Ann. Rept. Daly West Mining Co. for 1905, p. 5.

DEVELOPMENT.

The Daly West ground contains lenticular replacement ore bodies in limestones, dipping gently northward, and lode deposits in the Daly-Daly West fracture zone, dipping steeply northward. Accordingly two types of development are found. In general the limestone has been opened for a vertical distance of 1,000 feet (from the apex near the Quincy shaft to and below the 900-foot level) and a horizontal distance of 3,000 feet. The great lode has been opened vertically 650 feet and horizontally nearly 3,000 feet.

The main Daly West workings have been opened through a shaft 1,650 feet deep from which levels have been run at depths of 900, 1,200, and 1,400 feet. The 900-foot level, extending to the western limit of the property with two long crosscuts running south, constitutes the work level for the upper part of the mine, which embraces the workings in the beds in limestone. The Quincy shaft leads to levels turned at depths of 100, 200, 300, and 400 feet, and thence by a main incline with levels leading off at regular intervals to the upper levels of the Daly West. The lower workings of the Daly West, opened to develop the great lode north of the shaft, include three drifts at 1,200, 1,400, and 1,500 feet, which extend for the length of the lode within this property, and connecting inclines that are connected also with the workings of the Daly and of the Daly Judge. Excellent ventilation is obtained and the mine drainage, as in the other members of the series of properties, is eastward through the Ontario drain tunnel.

ECONOMIC GEOLOGY.

Character of country rock.—The country rock of the flat ore bodies is limestone of the Park City formation, and that of the lode ore is Weber quartzite and limestone of the Park City formation. At the surface important features of the formations in this ground are concealed by thick deposits of glacial material. South of the Daly West shaft, on the Quincy spur, the lower part of the Park City formation, including gray and cherty limestone, calcareous sandstone, and argillaceous members, outcrops dipping 22° NW. This is overlain on the west by argillaceous beds which probably belong to the red Woodside shale and have been metamorphosed together with the underlying sediments by an extensive body of diorite porphyry intruded from the south. Immediately west of the shaft a dike of diorite porphyry appears through the glacial deposits and below the moraines which in closing the gully on the west forced back the Lady Morgan Lakes. To the north the Woodside shale outcrops below limestone of the Thaynes formation, dipping 50° N. The concealment of bedrock in this area is particularly unfortunate in view of the desirability of tracing the main Ontario-Daly-Daly West lode and the faulting upon it. The extension of the cropping of the main Ontario lode westward from its supposed passage under the Daly boarding house would seem to pass up the slope opposite on the west side of Empire Canyon. If this is true a reversal of movement on the fault is indicated, as the offset of the contact between the Thaynes formation and the Woodside shale at the western locality is about 225 feet on the north. The main Ontario fault is believed by mining men, however, to have a more southerly trend and to pass up Empire Canyon. The last point where the branch of this lode that constitutes the main Daly-Daly West lode is traced at the surface is on the road about 700 feet east of Daly shaft No. 1 at the "apex raise." In Daly West ground southwest of the Daly West shaft a peculiar ridge with steep southward slope extends along the bottom of the gulch southwestward toward the Daly Judge shaft in the proper position and trend for the Ontario-Daly-Daly West fault. This situation suggests that if the ridge is not a moraine it may be determined by the fault. The position of the area of Woodside shale northwest of the Daly West shaft relative to that of the argillite (probably metamorphosed red shale) at the south side of the glacial blanket on the Quincy spur suggests an offset along the main fault zone toward the east on the south side. The surface rock reveals little regarding the country rock on this property beyond these general features.

Underground the Quincy and the upper levels of the Daly West lie in general in limestone of the Park City formation and the deeper levels along a fault contact between this formation and the Weber quartzite. Thus the limestone over the quartzite, dipping northward,

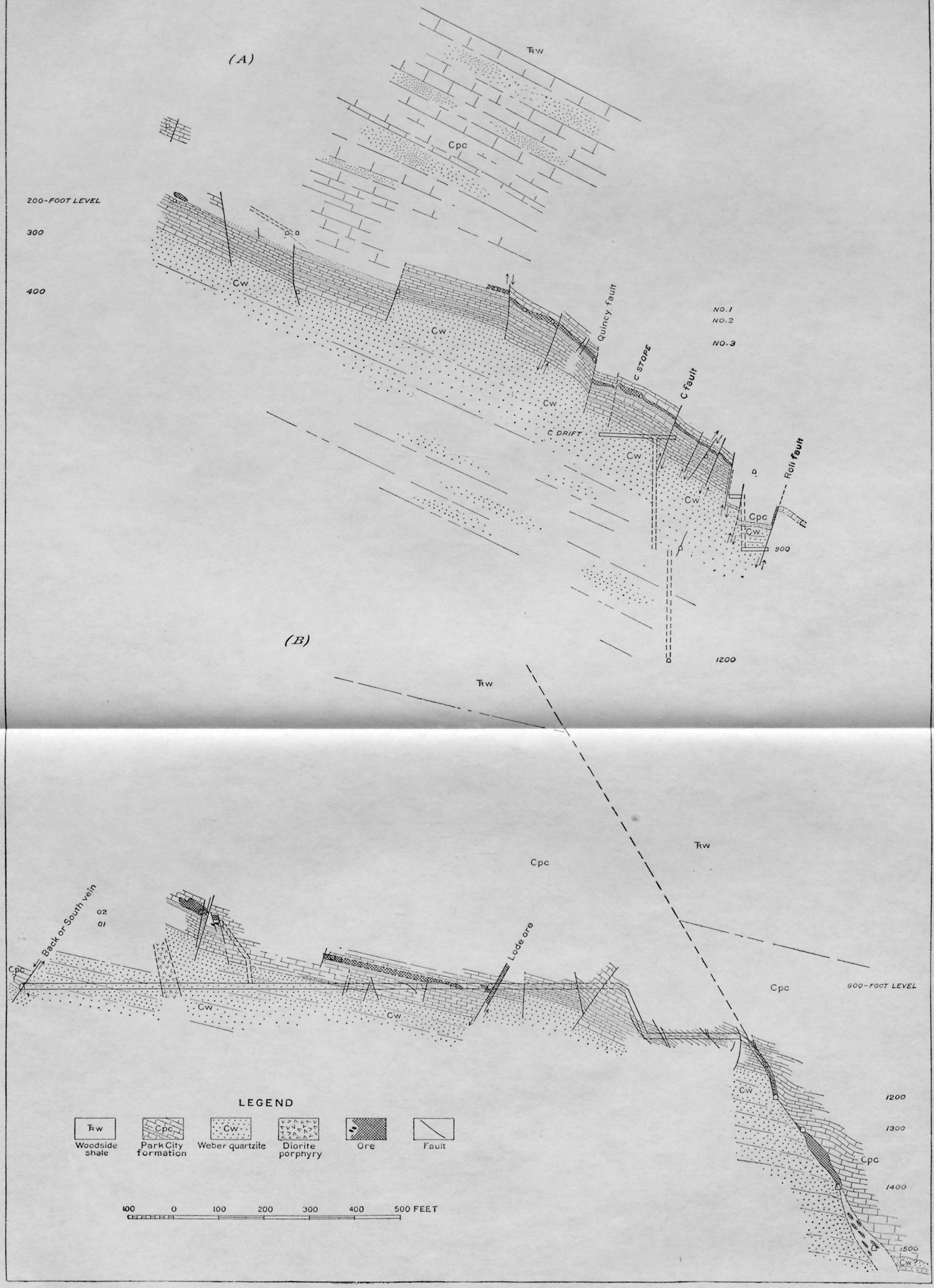
descends through the Quincy mine to the 900-foot level in the Daly West, where the main east-west drift lies in the Park City formation, which thence descends to the main lode. Two long crosscuts from the drift on the 900-foot level pass out of the limestone and enter the quartzite at distances of 75 and 500 feet. On the 1,200-foot level the crosscuts from the shaft to the southwest and north to the lode are entirely in Weber quartzite. North of the lode the prevailing rock is carbonaceous limestone, though on the 1,500-foot level in the eastern part quartzite is present.

At the extreme south side of the mine coarse andesite porphyry has been cut in masses 10 to 40 feet thick at several points—for example, in the Quincy in the shaft, in a crosscut south to the Little Bell, and in crosscuts to the west. In the Daly West these porphyry bodies are cut at the head of the Kirby raise, along the drift west from the raise, in the crosscut south from this drift, on the 1902 level west, and on the 900-foot level near the south faces of both south crosscuts. These occurrences appear to belong to a narrow dike, which trends in a general east-west course (commonly N. 75°–80° E.) and dips about 90°, locally to the south and at some points to the north.

The part played by this dike in the generation and the limitation of the ore deposits was regarded by the disputants as an essential factor in the settlement of the threatened litigation between the Daly West and Quincy companies. In the extreme northeastern part of the ground opened on the 1,500-foot level east of the main incline a dike is encountered 50 feet thick trending northwest.

Structure and deformation of country rock.—The Weber quartzite and the overlying limestone of the Park City formation normally dip northwestward and are traversed by a series of faults trending northeast and southwest. The dip ranges from 18° to 45° in directions N. 30° E. to N. 80° W.; thus in the vicinity of the Quincy shaft the limestone dips 30° and 35° N. 75° and 80° W.; near the head of the Kirby winze 35° N. 65° E.; on the 900-foot level of the Daly West, in the eastern long crosscut south, 35° N. 50°–60° W.; at the junction of the West drift with the western crosscut south, 30° N. 30° W.; to the west, 20° N. 50° W.; and at the north in the incline to the 1,200 foot level, 35° N. 20° W. (See Pl. XLII.) The northeast fissures comprise a zone, and the faulting on them varies in amount and in direction of movement. So far as development at the time of study revealed, they lie between the main Ontario fracture on the north and the Daly-Judge "back vein" fissure on the south and include in addition to these several other noteworthy faults, of which the more important appear to be the Roll fault zone, the C fault zone, and the Quincy fault. On the main Ontario fracture in Ontario ground the north wall descended 475 to 500 feet. The most important of the several "spur veins" that branch from this fracture toward the southwest and apparently are contemporaneous with it is the Daly-Daly West lode. In Daly West ground it appears that the limestone and quartzite contact, dipping into the fracture, is truncated by it at a depth of about 1,000 feet. The direction of movement appears to have been down on the north side, for limestone or carbonaceous beds generally form the hanging wall and quartzite the footwall. The amount and character of this displacement could not be precisely determined, however, as the exploration was not sufficient to prove the character and stratigraphic horizon of the formations constituting the hanging wall. Broadly, the hanging wall appears to be composed of limestone of the Park City formation, except at the east end of the 1,500-foot level and at one point on the 1,200-foot level, where quartzite which may or may not belong in the Park City formation is opened. It would thus appear that the hanging wall of the Daly West lode dropped from 350 to 500 feet.

The Roll fault, which at the elevation of the 900-foot level is about 500 feet south of the Daly West lode, strikes east and west and dips steeply to the south. Along the western long crosscut south on the 900-foot level and in adjacent stopes it appears to be a zone of fissures or a compound fracture. The fissure upon which the main displacement occurred is followed west by the water drift, where the dip ranges from 54° to 70° S. The drag here clearly indicates relative elevation on the north. This elevation produces the effect of an anticline, arch, or roll; hence the name Roll fault. The displacement was insufficient to elevate a recognizable



A. SECTION ALONG LINE OF WEST CROSSCUT SOUTH (N. 10° W.).

Shows occurrence of bedded ore along main ore-bearing member and of lode ore in main Daly West fracture zone.

B. SECTION THROUGH POINT 1,000 FEET SOUTH OF SHAFT.

Shows occurrence of bedded ore and ore-bearing series.

GEOLOGIC STRUCTURE SECTIONS THROUGH DALY WEST MINE.

datum (as the Weber quartzite) above the 900-foot level so as to afford a basis for precise determination of the amount, which probably did not exceed 50 feet at this point.

The C fault, named from the stope in which it is best exposed, is one of the Roll fault series, striking and dipping parallel to the main Roll fault about 250 to 300 feet southeast of it. The amount of dislocation on this fault could not be precisely determined, but is probably from 15 to 25 feet.

About 200 feet to the southeast, near the foot of the Kirby inclined winze, a fault is exposed which appears to constitute the southern boundary of the Roll fault zone. It is of opposite phase to the Roll fault, the movement being up relatively on the south, and thus it limits on this side a structural trough of which the Roll fault forms the northern wall. The amount of displacement could not be exactly observed, but if the bed of limestone in which ore was formed in each wall of the fault is the same stratigraphic member, the displacement is about 60 feet.

Though the faults opened on the '01 and '02 levels are clearly of the same general zone, the relation of these several faults in the eastern part of this ground with those in the western part opened on the '01 and '02 levels could not be positively determined, owing to the lack of necessary development at the time of visit.

In the western part of the Daly West ground, about 500 feet south of the '01 and '02 fissure zones, a fracture, known as the Back vein, has been opened in the Daly West and extensively in the Daly-Judge. At the south end of the western crosscut on the 900-foot level it strikes N. 50°–60° E. and dips 55°–70° S. The direction and the amount of dislocation which has taken place on this fault are undetermined, for although the north or foot wall is Weber quartzite and 60 to 70 feet of limestone is exposed in the hanging wall, it is not known whether this is an intercalated member in the Weber quartzite or a down-faulted portion of the limestone of the Park City formation. It is probable, however, that the south wall has been relatively dropped. The features above described comprise the more pronounced geologic structures observed in this property, though innumerable minor fissures and local structures are found which can not be treated here.

Croppings of ore bodies.—Croppings of the Daly West lode are not known, the probable position of its apex being masked by glacial deposits. The apex of the faulted limestone member in the Park City formation, which forms the locus of the bonanzas in Daly West ground, has been asserted by several persons to lie on Daly West, Quincy, Little Bell, and other ground still farther south. A raise at the east end of the Quincy 100-foot level, called the Apex raise, is stated to have followed the main shoot to the surface, but at the time of visit neither ore in this raise nor croppings were discernible. The main shoot is reliably stated to have been struck in the Quincy shaft at the 200-foot level. In connection with the threatened Quincy-Daly West suit and the recognition of the apex as determining ownership of ore, persons largely interested in the Daly West obtained a controlling interest in the Little Bell. An ore bed in the latter property is asserted on stratigraphic evidence to be the surfaceward extension of the Daly West ore-bearing limestone. This had not been proved by connection at the time of visit, and the cropping of that member on Little Bell ground or south of it is not known to have been positively determined.

Form of ore bodies.—The ore bodies are in general of tabular form, dipping gently if a replacement body in limestone or steeply if a lode. The flat bodies lie in limestone along a bed or beds as a rule immediately adjacent to or in the vicinity of a fissure or a fracture zone. The general form is that of a comparatively thin lens with irregular fingered margins. These lenses attain their maximum extent along the fractures, one in the Quincy reaching a length of 600 feet, and another, over the work drift on the 900-foot level, being 1,000 feet long. Some extend from the fractures in both walls for only a few inches, others several feet, and the largest more than 100 feet. The thickness of the lenses ranges from 2 to 15 feet, being perhaps in most of those worked 4 or 5 feet. The member in which the ore occurs is a bed of pure blue limestone overlying a thin, brownish, impure, shaly limestone. The latter rests upon a brown sandy member about 20 feet in thickness, which in places is only with difficulty distinguished from the Weber quartzite. The horizon at which the ore most commonly lies, however, is

about 40 feet above the Weber quartzite. In some places, as on the '01 level at the west end, the ore occurs in the limestone immediately over the Weber quartzite or at other unusual horizons. In other places the ore occurs in more than one member. Thus in stope C (see Pl. XLII, p. 152) a 15-foot bed of ore occurred upon a footwall of 4 feet of pseudoquartzite, which was in turn the hanging wall for a lower bed of ore 6 feet thick. This intervening barren member, called by the miners the "parting quartzite," is encountered at many points in this part of the mine. Near stope C also ore was made out along seven distinct limestone members adjacent to a fissure. (See under "Occurrence of the ores," p. 125.)

In the Quincy on the first level the ore appears to occur at the same horizon as in the Daly West, namely, over the false quartzite or, more exactly, over the 15 to 20 feet of brown sandstone, but the ground below is considerably faulted (N. 6° E.) and the precise horizon of the ore is less certain. In one place it is quite clear that the ore-bearing horizon is not the same as in the Daly West. In this place from 1 to 3 feet of blue cherty limestone immediately underlies the ore and 15 feet of blue siliceous limestone lies below that and upon the 20-foot brown sandstone member.

The fractures in the Quincy and the upper levels of the Daly West, including some of those adjacent to the above-described bedded ore, also inclose ore bodies. The main mass of lode ore, however, occurs in the main Daly-Daly West fracture zone. In general it lies along the zone, and within this it is localized into fairly well-defined shoots. Although bodies have been opened and stoped at several points, the bulk of the ore has been taken from two great shoots. One of these, at the extreme west end of the mine, has been stoped from the 1,200-foot level down to the 1,400-foot and is about 600 feet in length. At one point above the 1,400-foot level it is mined continuously for 255 feet and attains a width of 35 feet. The footwall was Weber quartzite, the hanging wall was black carbonaceous limestone, and the ore occurred in an 8-inch streak of zinc and lead immediately under the hanging wall, in a 6-inch streak of galena lying immediately upon the footwall, and in seams of sulphides scattered through the intervening portion, commonly in a gangue of quartz. In the bottom level the ore was found more commonly in isolated bunches and seams disseminated through a zone of intensely crushed silicified quartzite. The second shoot, lying north of the shaft, had been mined at the time of visit for a length of 300 feet on the 1,500-foot level and reached a width of 30 feet.

Character of ore.—The ore carries chiefly silver and lead, considerable zinc, and some copper and gold. The two types of occurrence mark corresponding mineralogic types and grades of ore. Thus high-grade (crude) ore has been derived mainly from replacement bodies in limestone and milling ore from the main Daly West lode. The same ore and gangue minerals are present in both types of ore, though in distinctly different forms and relative amounts. Thus the replacement ores in the Quincy and upper Daly West workings show thick, extensive bodies of solid metal made up of portions (1 to 2 inches across) of coarsely cleavable galena and tetrahedrite, though in some beds, as in stope A, comparatively small grains of these minerals are interspersed with resin zinc. The lode ore is more irregular, carrying bands of solid coarse cleavable galena and seams of granular galena with much resinous sphalerite. The gangue of both classes is quartz, which, especially in seams in lodes, is crystalline. Silver is found in galena, pyrite, tetrahedrite, and some in sphalerite. Galena and in much less degree the alteration products cerusite and anglesite form the source of the lead. Copper lies in tetrahedrite and pyrite, in small amounts of chalcopyrite, and (in the oxidized zone) in malachite and azurite. Zinc is usually in the form of massive granular resinous sphalerite, though some crystals are found. Pyrite, probably cupriferous, is present, usually in small grains but in comparatively insignificant amounts. The ores have not been oxidized to a very great depth in this ground. Thus in the Quincy oxidized ores are stated to have been worked out between the 200 and 300 foot levels. On the 400-foot, '01, and '02 levels oxidation is relatively unimportant, and below these the sulphides are unaltered.

DALY-JUDGE MINE.

SITUATION AND HISTORY.

The Daly-Judge mine is situated 2⅓ miles southwest of Park City, at the head of the southwest fork of Empire Canyon.

This property is the most extensive and includes some of the oldest workings in the district. The history of its development is a record of remarkable persistence through a most unusual succession of difficulties and disasters. The present holdings comprise a block of 138 patented claims, covering an area approximately 4,000 feet long and 15,000 feet wide, and embrace the Old Utah and White Pine mines, the Anchor mine, the Jones ground on the south, and a great tract of practically virgin ground on the southwest.

The trend of the Ontario lode naturally led to prospecting and locating along its possible southwest extension. Consequently the ground in the vicinity of the gap in the main divide was early taken up as the Utah claim on the south or Bonanza Flat side of the pass and the White Pine claim in the gap and on its north slope. On the White Pine, which was thus one of the earliest locations in the district, a shaft was sunk 100 feet and ore was struck as early as 1878. Regular shipments were made and dividends paid in 1881. In 1882 ore had been opened on the 100, 200, and 300 foot levels and a pump had been installed on the 400 foot level. In 1883 a new shaft was sunk on the north slope. As early as 1881 the Utah shaft had been sunk to a depth of 340 feet and in 1883 it had reached 450 feet. These successful operations stimulated work in this locality, and in 1883 Anchor ground, immediately to the north, was being developed. On March 25, 1885, the White Pine, Utah, and Anchor properties were consolidated and the Anchor Mining Co. was formed. Extensive surface improvements were made, and in August of that year the Anchor shaft was started. This progressed rapidly, despite serious interference from water, until about the middle of the next year, when a heavy flow of water was encountered at the 600-foot level. This, with the added waters of the melting snow, proved too much to handle, and in the spring of 1887 work in the shaft was suspended. In the following August a drain tunnel was started from a point in Empire Canyon about 6,600 feet to the northeast, which would pass below the collar of the Anchor shaft at a depth of 1,200 feet. The dimensions of the tunnel were 5-foot sill, 4 foot cap, 7-foot post, with flume below sill 3 feet wide and 2 feet deep; the grade was three fourths of an inch to a rod. The extension of the tunnel to a point beneath the shaft failed to drain the water. Accordingly a 6-inch bore hole was started to pierce the 600 feet of rock intervening between the bottom of the shaft and the drain tunnel. In January, 1890, the hoist, which had been damaged during the preceding winter by a heavy snowslide, was consumed by fire. Boring was soon resumed, but after progressing 300 feet was abandoned because of the loss of the bit, and boring upward from the tunnel was begun. After reaching a point 50 feet below the bottom of the shaft without drawing the water, a torpedo was there exploded but without success, and it was not until the boring was pushed upward within 20 feet of the bottom of the shaft that the desired drainage was finally effected. A new hoist was erected in May, 1891, and in September of the following year the shaft was connected with the drain tunnel. Shipments of ore were begun in July, 1890, and increased through the fall, and during the succeeding two years this mine ranked with the Ontario and the Daly as one of the chief producers of the district. After the general lull in 1893 work was resumed on the property in October of that year and was actively prosecuted in 1894, this mine being at one time the only shipper in the district. Since then development and production have gone on subject to the usual fluctuations.

In 1899 the alleged extraction of ore by the Anchor Mining Co. from the ground of the Daly West Mining Co., gave rise to litigation, which was adjusted by the payment of $12,500 by the Anchor Co.

The concentration of the second-class ore has been attended by considerable difficulty, but persistent experimenting brought a satisfactory solution of the problem. In 1890 the Union mill in Empire Canyon, on the outskirts of Park City, undertook the concentration of Anchor milling ores. After patient work with these refractory ores and a succession of improvements

resulting in a fairly satisfactory process, a new and much larger mill was built opposite the mouth of the drain and work tunnel, thus eliminating intermediate handling.

In November, 1901, the Daly-Judge Mining Co. was organized, and in April, 1902, the consolidation of the holdings of that company was consummated. The property both underground and on the surface was extensively improved with a view to a general increase in operations, especially to handling a greater tonnage at lower cost. The mill, for example, after some tests was reconstructed and enlarged from a capacity of 100 to 300 tons a day. In 1903 operations were resumed for a period, then shipping was stopped, the mill again altered, and a vigorous campaign of underground development was begun. In 1906, after 23 months of improvement work, production was resumed, and the results of 10 months' shipments were sufficient to wipe out indebtedness and leave a good balance. This successful operation was unfortunately interrupted by the general stringency of money and curtailment of business in the country in the fall of 1907. Pending a return of conditions warranting the resumption of active production, operations were devoted to systematic underground exploration and development.

PRODUCTION.

The ores produced from Daly-Judge ground to January 1, 1908, amounted to 167,784 tons and sold for $4,189,234. The details of production and values are shown in the following statements, based on data kindly furnished by the company.

The total production of the Anchor mine was 94,639 tons of dry concentrates, which sold for $2,417,368.30, an average of $25.54 a ton. These are the net proceeds received from the smelters for all ore shipped, after deducting the charges for freight and treatment. The average assay was 41 per cent of lead, 25.67 ounces of silver to the ton, 0.043 ounces of gold to the ton, and 8.87 per cent of zinc.

Production of Daly-Judge mine to January 1, 1908.

Year.	Silver, ounces.	Gold, ounces.	Lead, pounds.	Zinc, pounds.	Copper, pounds.	Sold for—
To Dec. 31, 1902 [a]						$2,417,368.30
1903	454,248	929.42	13,244,612			400,489.88
1904	35,631	80.98	1,240,799	143,529		44,215.91
1905	34,369	86.17	361,412	1,863,980		19,112.32
1906	544,098	2,448.17	14,144,954	10,180,751	156,110	815,258.13
1907	322,489	1,256.10	9,788,680	5,039,582	116,793	492,790.14
	1,390,835	4,800.84	38,780,457	17,227,842	272,903	4,189,234.68

[a] By Anchor Mining Co.

PLANT.

The equipment of the Daly-Judge includes a complete hoisting outfit at the collar of the 1,600-foot shaft, an air compressor, and accommodations for housing and feeding its miners. The work and drain tunnel through which the output of the mine is trammed is equipped for heavy electric haulage. At the mouth of the tunnel are the usual workshops, also the mill. The latter is thoroughly equipped on the general lines of the Daly West mill to treat 300 tons of ore a day and to produce lead-silver concentrates and iron-zinc middlings. These middlings, which have been the subject of many experiments, have been treated by magnetic concentration at the Peck mill in lower Park City and by the electrostatic separation process employed by the Western Ore Separating Co. at its Salt Lake plant and were to be handled at a plant for magnetic separation erected by the Grasselli Chemical Co. at Park City.

DEVELOPMENT.

The northeastern part of this company's extensive property has been widely explored. That portion immediately adjoining the Daly West ground has been opened by a shaft 1,600 feet deep and crosscut by levels at depths of 500, 700, 1,200, 1,400, 1,500, and 1,600 feet in a general north-south direction (parallel to the Daly West-Daly-Judge line) through a distance of

2,100 feet. The ground southwest of the shaft has been opened on the 500, 700, 1,200, 1,300, 1,400, and 1,500 foot levels for approximately 1,000 feet and on the 1,200 and 1,400 foot levels for more than 3,000 feet. In short, an area embracing the northeastern part of this property, approximately 2,100 by 3,000 feet in dimensions, has been opened, besides which the work and drain tunnel extends 6,600 feet northeast of the shaft, making crosscut workings on the 1,200-foot level from its west face to the mouth of the work nearly 10,000 feet in length.

ECONOMIC GEOLOGY.

Character of country rock.—The geologic formations exposed on this property are the Weber quartzite, the Park City formation, the Thaynes formation, shales probably of both the Woodside and the Ankareh formations, diorite, and diorite porphyry. In general, the ground includes the southwestern extension of these sedimentary formations where they are traversed by the main northeast-southwest zone of mineralization and are truncated on the southwest by the Clayton Peak mass of diorite. The rocks are highly metamorphosed and deformed and along the southwest fork of Empire Canyon they are covered by glacial moraines and kames.

The picturesque divide which overlooks the Daly-Judge amphitheater from the south is made up of highly metamorphosed argillaceous and calcareous beds largely if not entirely of Triassic age (Thaynes formation). Fossils are very scarce in this locality, but near the base of this series a few were found belonging to the Triassic fauna, which indicate that the beds in this ridge on the west are probably of that age. North of the Daly-Judge shaft and exposed by grading for the road and for the office and bunk-house building are metamorphic limestones in which the writer found fossil remains of Triassic age. Northeast of the shaft these limestones and sandstones have been invaded by a strong dike of coarse diorite porphyry. Overlying this Triassic formation are varicolored metamorphosed shales of the Ankareh shale, and these are truncated on the southwest by an arm of the main diorite mass of Clayton Peak. Underground the mine workings show in general metamorphic calcareous sediments to a depth of 1,400 feet at the shaft and Weber quartzite below cut by diorite porphyry. Some green and red shale is cut by the main drift running west on the 700-foot level. The exceptional thickness of limestone exceeding the thickest measured series of limestones in this camp is apparent only and is due to faulting.

Structure and deformation of country rock.—The broad structure of these formations is monoclinal, with a dip of 20°–40° NW., averaging about 22°. This structure is broken by a part of the main zone of northeast-southwest fissures, which dip as a rule steeply to the north, but in certain places to the south. The displacement on them ranges up to several hundred feet. In the vicinity of the stronger faults the prevailing dip mentioned above is in places highly disturbed, being dragged to 70° N. or reversed to flat southerly dips.

In general the dominating fissures and displacements are southwestern extensions of those described in the section on the Daly West mine (pp. 152–153). The principal members are the main Daly-Daly West-Daly-Judge fissure, the southward-dipping Roll fault, and the Back vein. The Daly West-Daly-Judge fissure, the master fault of this northeast series, has been opened on the 500-foot level immediately south of the shaft striking N. 55°–60° E. and dipping 70° NW., and is apparently penetrated by the shaft nearly to the 700-foot level, where a strong N. 60° E. fissure (doubtless the footwall of this zone) descends just north of the station. On the 1,200-foot level this fault is believed to be indicated at a place in the work tunnel about 225 feet east of the shaft, where a strong northeast-southwest fracture crosses, is reported to have been cut by a crosscut at a point (inaccessible at time of visit) 150 feet north of the station, and to have been developed in 1907 for 1,000 feet beyond toward the southwest. A strong fissure, which has usually been regarded as the Daly West-Daly-Judge vein, is stated to have been cut north of the shaft on the 1,600-foot level.

No satisfactory opportunity to determine the displacement on this fault zone was found. The scanty evidence exposed by the drain and work tunnel east of the shaft, where the rocks are mainly red shale in the hanging wall and metamorphic limestone in the footwall, suggests

that the hanging wall descended sufficiently to bring the Woodside shale opposite the Park City formation, indicating a dip of a few hundred feet, as appeared to be the case on the east in Daly West ground.

On the 500-foot level the strike was well shown to be N. 55°–60° E. and the dip 70° NW., and the direction of movement was indicated by strongly developed slickensides to have been about parallel with the dip. These facts and this interpretation of them throws light on the great thickness of limestone cut by the Daly-Judge shaft. It thus seems probable that on the fault zone traversed by the shaft between the 500 and 700 foot levels the limestone shown by fossils at the collar of the shaft to belong to the Thaynes formation has been dropped well down toward the Park City formation, which in the footwall and overlying the Weber quartzite is penetrated by the shaft for most of the distance from the fault down to the quartzite. The shale in the 700-foot level doubtless overlies the Park City formation and is the Woodside shale. Thus the abnormal thickness of limestone penetrated by the Daly-Judge shaft, which has been held by some to belong entirely to the Thaynes formation and to show a local thickening of that formation, appears rather to be composed of limestone of the Thaynes formation only in the upper part of the shaft, or down to the fault zone, and of limestone of the Park City formation in the lower part on the footwall side, with probably some metamorphosed Woodside shale lying on the Park City formation immediately under the fault zone.

South of this main zone several strong parallel fissure zones have been opened, notably one which on the 1,200-foot level 180 feet south of the shaft, dipping 64° S. with a downthrow on the south, appears to be equivalent to the Roll fault in Daly West ground, and a strong northeast-southwest zone which, standing vertical or dipping to the south, has been followed far to the west on the 1,400 and 1,500 foot levels; also a parallel zone which at a distance of about 1,000 feet south of the shaft has been extensively explored on the 1,200 and 1,250 foot levels. This is equivalent to the zone opened in Daly West ground on the '02 and '03 levels. Still farther south, about 1,500 feet from the shaft, a well-defined persistent southward-dipping fracture zone has been opened on the 700, 1,200, and 1,400 foot levels and has been followed continuously between these levels. This strikes N. 60° E. and dips 60°–80° S., growing somewhat steeper in depth. On the 700-foot level both walls are metamorphosed limestone or shale, probably Park City formation in the footwall and Thaynes in the hanging wall. On the intermediate level running from No. 3 raise next above the 1,200-foot level, at an interval of 100 feet, and from these down to the 1,400-foot level, Weber quartzite occupies the footwall. A downthrow of at least 1,000 feet on the south would thus appear to be shown. The formation cut in exploration on the lower levels at the southwest are Weber quartzite and its intercalated calcareous members and overlying limestone of the Park City formation. Farther southwest diorite will probably be encountered, though not necessarily at the same distance as its outcrop.

In short, the general structure is that of long, narrow fault blocks, marked on the north by the Daly West-Daly-Judge fault of several hundred feet downthrow and on the south by the Back vein fault of several hundred feet downthrow on the south side and several strong intervening fault zones. In all these blocks the upper part consists of limestone of the Thaynes formation and the lower is made up of limestone of the Park City formation and Weber quartzite, Woodside shale being almost all cut out by faulting in the vicinity of the shaft.

The character of the deformation and the direction and amount of dislocations connected with the lesser faults can be determined in the same manner as has been done for the major features in the foregoing sketch.

Ore bodies.—Both lode and replacement deposits have been opened in this ground. The principal bedded ore bodies have been found adjacent to the Daly West line, but some of them extend many hundred feet to the southwest. Thus the great flat ore body which was stoped extensively on and above the 900-foot level in the Daly West has been followed westward and worked to a considerable extent on the Daly-Judge side of the line. In this place the ore appears to lie in sheets elongated and pitching generally northward with the dip of the beds.

The more important lodes are the Daly West-Daly-Judge, the Back vein, and two lying intermediate between these, one a few hundred feet south of the Daly-Judge lode and the other

farther south about midway between this and the Back vein. The Daly-Judge lode, the westward extension of the main Daly West lode, has been explored on the 500-foot, 1,200-foot, and (as reported) 1,600-foot levels. On the 500-foot level it was found east of the shaft to be a strong fracture zone from 6 to 10 feet wide between walls of iron-stained sandy limestone. Immediately south of the station the fracture zone attains twice that width and on the west the fissures carry carbonate ore of lead and copper between silicified walls, the whole being much stained with iron and manganese. On the 1,200-foot level no ore was seen, but it was stated by those in charge at the time of visit that at the intersection of the lode by the drain tunnel, east of the shaft, considerable ore was stoped and that north of the shaft the fracture zone continued strong.

It is authoritatively reported that in 1906 and 1907 (since the writer's visit) the extension of this lode westward was explored through a drift driven parallel to it for 1,000 feet, 30 feet back in the footwall, and through crosscuts to the lode in one of which "a very good grade of mill ore about 15 feet wide" was cut, and in another, 250 feet distant, shipping ore carrying good percentages of lead, silver, copper, and zinc was opened. The lode is also reported to have been cut on the 1,600-foot level north of the shaft.

The Back vein, which lies at the south side of the ground thus far explored, has been opened on the 700, 1,200, and 1,400 foot and on four intermediate levels and followed from the 700-foot to the 1,400-foot level. Adjacent to the Daly West ground, from a point about 80 feet below the 700-foot down to the 1,200-foot level, a large amount of excellent lead-silver ore was stoped. To the west it appears as a strong fissure or fracture zone, which strikes about N. 60° E. and dips 55° to 80° S. At points on the 1,400-foot level it shows 2 feet of good lead-sulphide ore in an iron and quartz gangue, the whole crushed by postmineral movement, but up to the time of visit nothing had been found comparable with the shoot at the extreme east end. The vein which has been opened on the 1,400 and 1,500 foot levels in the footwall of the Daly-Judge lode has given good indications at several points and has afforded small bodies of good ore. The mineralized zone lying between these lodes and the Back vein in the western extension of the '02 and '01 zones of the Daly West has been opened on the 1,200 and 1,250 foot and intermediate levels. On the 1,200-foot some good lead ore, with considerable iron and zinc, has been found in calcareous beds adjacent to a strong southward-dipping fracture zone, and immediately north of this, in direct continuation of the Daly West '02 ore zone, good silver-lead ore, somewhat zincky, occurs in northeast fissures and has been stoped through a considerable extent from beds 1 to 4 feet thick. Since one period of fissuring and the deposition of ore in the fissures and in beds, another epoch of fracturing has occurred which has crushed the fissure ore and offset the bedded ore.

In brief, the ore in the Daly-Judge ground occurs in a zone of Carboniferous limestones, adjoining an extensive stock of diorite either in northeast-southwest fissures or in limestone beds adjoining them as zinciferous silver-lead lode and replacement ores.

Character and tenor of ore.—The ores of the Daly-Judge mine are silver-lead ores of both shipping and milling grade, with considerable accessory zinc in a quartz or calcite gangue. Some granular pyrite and scattered bunches of tetrahedrite are associated with both the fissure and the replacement ores. A little gold occurs, as shown in the following tables. The concentrates from milling ore distinctly exceed the first-class ore. The vugs in some of the fissures are walled with zinc and coated inside with calcite and intergrown quartz and galena crystals, and this coating is overlain by zinc crystals. In other vugs the walls are covered with large infacing quartz crystals, interspersed with zinc crystals. At the 500-foot level oxidation has proceeded far in producing carbonates, and some of the fissure ores have been oxidized even to depths of 1,200 and 1,400 feet, yielding azurite, black copper oxide, and chrysocolla, but the ores of the lower or active part of the mine are virtually sulphide. The bodies opened in later years in the deep western portion of the property, mainly in quartzite, are noteworthy for their general high grade and freedom from zinc, with higher gold tenor. As a whole, however, the Daly-Judge ores have been somewhat high in zinc. This feature, which for many years handicapped the property, has now been turned to good advantage by saving a zinc-middling product that affords a valuable income.

The exact amount and proportion of the several metals in the ore, together with their value, are shown in the following table prepared from data furnished by the company:

Production and average value of ore per ton from the Daly-Judge mine.

Crude ore.

Year.	Tons, dry.	Silver, ounces.	Gold, ounces.	Lead, per cent.	Copper, per cent.	Zinc, per cent.	Iron, per cent.	Sold for—
1903	2,536	23.24	0.043	16.75	.....	13.00	9.90	$14.50
1906	13,011	20.67	.091	24.61	0.41	14.62	16.04	28.72
1907	7,933	16.05	.056	18.61	.33	14.80	14.06	19.48

Concentrates.

To 1903	94,639	25.67	0.043	41.00	.....	8.87	.....	$25.54
1903	11,818	28.72	.062	43.91	.....	7.40	29.67	29.67
1904	1,218	29.20	.068	51.00	.....	6.00	12.60	36.38
1906	9,838	18.40	.070	33.33	0.17	7.00	19.64	36.71
1907	9,625	16.30	.058	31.08	.19	7.98	21.27	29.10

Zinc middlings.

1905	3,794	9.14	0.023	4.70	.....	25.11	16.57	$5.04
1906	4,490	8.22	.025	4.20	.....	25.03	16.98	5.95
1907	170	6.30	.025	3.70	.....	26.13	19.15	3.43

Iron middlings.

1906	2,713	7.64	0.044	7.60	0.32	9.87	31.10	$10.05
1907	5,999	6.20	.040	7.00	.22	9.00	32.08	7.96

ONTARIO CANYON.

GEOLOGIC FEATURES.

The general geology of Ontario and Empire canyons and the special features of the Ontario fissure system have been already described introductory to the detailed descriptions of the great mines located upon that system. Ontario Canyon descends from the main easterly spur of the range, taking a northerly direction to the junction with its companion valleys at Park City. From a broad, flaring upper portion it contracts to a narrow, steep-sided section, which opens on a bench of recent material, and thence turns slightly to the northwest and descends at a rather high gradient as a narrow, steep-walled canyon. These successive changes in the topography correspond with changes in the bedrock and its structure.

The flaring headward portion has been eroded out of the main stock of diorite porphyry, and the narrow, steep-sided parts in its middle and lower courses are cut in massive Weber quartzite. The interruption of its descent at Wabash and Lake Flat is in the vicinity of intrusions and in the general course of a strong zone of faulting and brecciation marked by the Ontario zone on the west and the McHenry zone on the east. Development shows that intrusive masses in this general region are more extensive underground than at the surface.

The general dip of the quartzite is northerly, as a rule northwesterly, but in the lower part of the east side northeasterly. The region throughout is traversed by fractures, among which, of course, the Ontario is the master. In the footwall of the Ontario fracture zone is a series of east-west fissures, and south of these on the northwest slope of Bald Mountain are several trending northeast and dipping southeast.

These fractures have been the main field of exploration in this area, and thus far appear to be the principal places for ore. Considerable prospecting has been done in the area, and several mines have been opened, some of which are producers.

PARLEYS PARK SHAFT.

The Parleys Park shaft is situated in Ontario Canyon at the head of Lake Flat, about one-fourth of a mile east-southeast of Ontario shaft No. 2.

In the early eighties, when the Ontario mine was proving so rich and exploration was active for the eastward continuation of the great Ontario lode, the ground next east was taken up under the name Parleys Park. Sinking was vigorously undertaken and by September, 1881, the shaft was down 318 feet, in November 425 feet, and in December 500 feet. In January, 1882, much water was encountered at a depth of 600 feet, which continued to be a serious obstacle. Sinking was prosecuted, however, it is understood, until a depth of 1,000 feet was reached.

No systematic drifting is known to have been done. The writer is reliably informed, however, that the shaft was connected with the Ontario 600-foot level. Some prospecting was also done on the Parleys Park 300-foot level. In 1884, after the Ontario vein had been sought without success, work was abandoned, the pumps were pulled, and the property was deserted. For 25 years it has remained idle.

This ground lies in the general central area of Weber quartzite at the core of the Park City anticline. It is traversed in this vicinity by east-west fractures, some of which are iron stained. The dump showed pieces of diorite porphyry. It is stated that the shaft cut some stringers that carried good ore, and that in the exploration a few pockets of rich material were encountered. From such meager indirect information as can be obtained it may be safely assumed that no ore of commercial value was found.

WABASH PROPERTY.

The Wabash ground is situated in Ontario Canyon immediately south and southeast of the Ontario ground (2,700 feet southeast of Ontario shaft No. 3) and the Wabash shaft is 900 feet south of United States landmark No. 1.

This property, comprising about half a dozen claims, is one of the group of properties that were taken up during the boom in the early nineties. In September, 1901, active work was started on surface improvements preparatory to a vigorous campaign of exploration, which was begun soon afterward. It was generally understood that the first objective point was ground north of the shaft in which the eastward continuation of the Ontario lode was believed to lie. That point and others were investigated in the course of the extensive exploration that has been done, and at last accounts ore had been found.

At the time of the examination of this property (December, 1903) the development comprised a shaft 820 feet in depth, with stations at 300 and 600 feet, and an extension at 600 feet. The principal drifting had been done toward the north, northeast, west, and southwest. During the following year work was done on the 300-foot level by drifting north and on the 600-foot level at the extreme southwest.

The Wabash ground is situated geologically in an area of possibilities, being immediately in the footwall of the Ontario lode, adjacent to an extensive outcrop of porphyry, and roughly in the line of the Hawkeye-McHenry fault zone. The prevailing formation outcropping on this ground is the Weber quartzite. The flat beneath which the shaft descends and on which the surface improvements are situated is formed of recent material, which entirely hides the underlying bedrock. Rising from this on the east is a large mass of diorite porphyry, which extends eastward and southward across the head of McHenry Canyon and connects near the Wasatch mine with the great crescentic mass encircling Bald Mountain. Just south of the Wabash flat metamorphosed calcareous sediments are exposed beside the mouth of the Naildriver tunnel.

Limestone and diorite porphyry are the prevailing formations underground, and in one locality quartzite was finally opened. The shaft is reported to descend through a zone of crushed rock to the station at the 300-foot level, where marble appears in the footwall and crushed quartzite with some marble in the hanging wall of a strong fracture trending N. 18° E. and dipping 61° NW. The marble extends to a depth of 636 feet, where the shaft enters diorite

porphyry, dipping gently northward, and continues in it to the bottom (at 820 feet). The 600-foot level, through which this property has been developed, traverses limestone chiefly but passes north from the station through 450 feet of diorite porphyry and thence an east drift traverses porphyry for the remainder of its course, 350 feet. West of the shaft the drift cuts four dikes, 5 to 40 feet wide, and within a short distance two more. These masses appear to be dikes with steep contacts trending either northward or northeastward and locally dipping northward. The 300-foot level revealed the quartzite overlying limestone north of the shaft, and a drift driven from the bottom of the shaft southward continued for its entire length of 400 feet in porphyry.

The limestone is normally fine grained, dark blue-black, in some places cherty, in others shaly, as well exhibited in the long exploratory drift toward the southwest. In the vicinity of the intrusives adjacent to the shaft, also toward the northeast and west, the normal limestone gives way to the metamorphic type, marble. No quartzite was found except that cut by the 300-foot level running north and that entered by the drift on the 600-foot level toward the southwest.

In the main mass of sediments cut underground the prevailing dip of those lying to the southwest is 20°–30° SW. At the north the dip of the metamorphosed beds has been seriously disturbed by intrusives and fracturing. The fractures trend in nearly every direction, but those north and west of the shaft characteristically strike N. 60°–75° E. and dip steeply, some to the north, some to the south. Southwest of the shaft the most common direction of the stronger fractures is northeast, with a dip to northwest. In this section considerable shearing and crumpling occurs, and at one point quaquaversal dips indicate a low doming.

The presence of limestone exposed by these workings and its abnormal structure call for explanation. The limestone is clearly not of the Park City formation but is geologically older than much of it. If not of the main limestone formation underlying the entire Weber quartzite it would appear to be an intercalated member in the Weber. The existence of considerable beds of limestone apparently intercalated in the Weber quartzite in the southeastern part of this district, north and south of Cottonwood Canyon, lends weight to this supposition. The many indications of confusion in the limestones at the southwest and their reversed dip and doming agree with the evidence afforded by the character and extent of the metamorphism in tending to show the extension of the main porphyry mass far enough southwestward to be effective at least 900 to 1,000 feet southwest of the shaft.

Surface mineralization, which is understood to have contributed in guiding the location of the shaft and the exploratory work, affected several east-west and northeast-southwest fractures, some of which showed iron staining. Underground very good indications have been opened at several places and some ore has been found. The main fissure zone, which was encountered about 500 feet north of the shaft, trending N. 60°–75° E. and dipping 50°–65° N., showed mineralization at several points. About north of the shaft it holds between porphyry walls a vein of quartz 2 to 5 inches wide with linings of infacing quartz crystals and limonitic and manganiferous patches. This vein is stated to have yielded 12 ounces to the ton in silver. In the same zone about 100 feet farther west, under a porphyry hanging wall, marble shows considerable granular cupriferous pyrite associated with contact-metamorphic silicates, such as garnet and chlorite, and about the same distance to the south is a similar occurrence and association. To the east this fracture zone shows highly iron-stained breccia.

The main porphyry mass crossed by the drift running north from the shaft is traversed by a succession of zones of sheeting and fracturing parallel to the main zone described immediately above. In the vicinity of these zones the porphyry shows some alteration and an increase in disseminated cupriferous pyrite. It is stated by the manager that material from the strongest of these zones lying about 350 feet north of the shaft yielded 8 ounces in silver.

Work west of the shaft has exposed similar disseminated cupriferous pyrite, fracture zones in porphyry and in one place along a bed of limestone, and strong fracture zones showing considerable staining.

These occurrences of cupriferous pyrite and well-stained fractures in porphyry and marble were the most favorable indications observed. Since the time of visit the manager has informed

the writer that exploration far to the south and west developed a fracture zone between limestone and porphyry which carried a high-grade sulphide lead-silver ore. In the gangue of a specimen which was sent by the company to Mr. Lindgren and which is believed to have come from this fracture, he discovered abundant gypsum.

NAILDRIVER MINE.

The Naildriver mine is situated in Ontario Canyon, mainly on the east side, immediately south of the Wabash mine and north and east of the New York ground. The shaft on this property lies in the slopes of Bald Mountain about 700 feet east of the creek bed and 400 feet east of the New York shaft.

The Naildriver claim was located in the early days of the camp by one of the few old pioneer prospectors who was still alive and in the camp during the present examination, Jack Creen. It was opened by him and proved to include a strong lode with some rich ore but awaited capital for suitable development. In 1902 the holders of ground in this vicinity, including the Ontario Mining Co., Mr. Creen, and others, consolidated their holdings as the Naildriver Mining Co. under the management of officials of the Ontario Co. It was capitalized on a basis of 300,000 shares at $2 a share, and the Ontario Co. received 90,000 shares as its portion. After some exploration from the old workings arrangements were made for sinking a double-compartment shaft with manway. The powerful hoisting plant of the Daly No. 2 shaft was transferred to this shaft and installed. During its first year the new company made three shipments of 45, 20, and 15 tons, which are understood to have been of excellent quality.

The old tunnel extends southeastward from Ontario Canyon about 900 feet to the main ore zone, which has been opened for about 900 feet along its strike on the tunnel level, for 50 feet from a point 85 feet down the incline below the tunnel level, by a number of short drifts off a vertical 100-foot winze below the tunnel level, the bottom level being 250 feet in length, and finallly by numerous short crosscuts and proof drifts. The shaft, starting at a point on the overlying slope 366 feet higher than the mouth of the tunnel, had been sunk 688 feet at the time of visit and connected at the 400-foot (348) level with the workings at the tunnel level. The object in thus sinking is stated to be to crosscut the ore zone below the point where it was so well developed on the tunnel level and on the level off the foot of the winze 100 feet lower.

Geologically the property is situated in the extensive area of Weber quartzite that occupies the axis of the Park City anticline. In the vicinity an extensive mass of diorite porphyry has invaded the quartzite in a general east-west direction. The exploration work is thus practically in a contact zone of sediments bordering this intrusive on the south.

Underground the prevailing formation traversed is Weber quartzite, though considerable marbleized limestone and small masses of porphyry are encountered. The general dip of the sediments is 15°–20° S., 35°–40° E. These rocks are greatly fractured and disturbed, especially adjacent to the main ore zone.. These generalizations are subject to many modifications.

The tunnel cuts marble in its outer 350 feet, and thence to the vein (about 550 feet) traverses quartzite except for a small irregular body of porphyry and a 6-foot sill. It was stated by the operators that the Naildriver shaft descended continuously through quartzite (except for 50 feet of limestone at a depth of about 350 feet) for 600 feet, and that thence to the foot at 688 feet it passed through marble. In the workings in the main zone also porphyry is found, as in the northeast drift, in the form of a 2-foot sill; in a crosscut on the east; and on the lowest level off the winze in a crosscut east to the vein, where it takes the form of an irregular mass breaking through quartzite. The strike also varies at one point in each face of the tunnel, being N. 70° E., with a dip of 29° and nearly N. 77° E., with a dip of 30°. The numerous fissures traversing this ground vary much not only in strike but also in dip—dipping both to the north and the south.

The main location of the ore is a strong fracture zone which at the level of the tunnel lies about 900 feet southeast from its mouth. It strikes generally east-northeast, varying from N. 55° E. to east and west, and dips toward the south at 45° to 85°, probably averaging about 50°.

At some points it appears as a well-defined fissure with sharp walls, as on the bottom level off the winze near the east and west faces, also on the tunnel level between the winze and tunnel. At other points it is a zone of crushing and fracturing without distinct fissures or walls, as at the east face of the bottom level off the winze. The walls of the fissures and breccia zone and the material of the breccia are commonly Weber quartzite. At the west face of the bottom level off the winze, however, marble and a few small lenses or bunches of porphyry are encountered within the fracture zone.

The ground in this immediate vicinity, particularly the ore zone and its walls, is highly stained and incrusted with iron and manganese. Within this most crushed and stained portion the ore occurs in bunches, as at the east face of the main stope and in broken bands, as at the north face of the 25-foot level of the winze and the east face of the bottom level. Localization of this ore into shoots had not been demonstrated by the development at the time of visit.

An excellent grade of oxidized and partly oxidized lead-silver ore is found. Galena, anglesite, and considerable cerusite and zinc oxide were noted, also a little malachite. The largest shipment made during the first year of the new company's operations is stated by the managers to have yielded 150 ounces of silver to the ton and 40 per cent of lead and the next largest 180 ounces of silver and 40 per cent of lead.

NEW YORK MINE.

The New York mine is situated in upper Ontario Canyon on the northeast slope of Bald Mountain, 1 mile south-southeast of the Ontario No. 3 shaft, two-fifths of a mile south of United States land monument No. 1, and immediately south and west of the Naildriver ground. The shaft is situated about 300 feet east of the main creek bed in the canyon.

It comprises half a dozen patented claims, which in early times had been only slightly opened. Thus in December, 1888, a lower and an upper tunnel had reached only 80 and 70 feet, respectively. During the great activity of 1903–4, when many companies were organized to mine in Park City, this ground was taken by the New York Bonanza Co. Local residents took the larger part of the stock and the development was placed under the direction of experienced mining men of the district. Sinking and drifting at successive levels were pressed with vigor and good ore was discovered. Development has been regularly continued and some shipments of excellent ore have been made.

The ground is opened through a double-compartment shaft and levels have been turned at depths of 200, 300, and 400 feet. From the 400-foot level winzes have been sunk and levels have been driven at 500 and 600 feet. Since the writer's last visit, it is understood, a 700-foot level has been driven. The 200-foot level extends northeasterly somewhat over 100 feet; the 300-foot northeasterly, southwesterly, and southeasterly a little over 100 feet in each direction; the 400-foot level southeasterly about 900 feet, northerly 300 feet, and northeasterly about 700 feet; and levels from the winze extend northeast and southwest for a total of several hundred feet.

The property lies geologically in an area of Weber quartzite, which has been fractured in northeast-southwest, northwest-southeast, and north-south directions and intruded to a small extent by diorite porphyry. The prevailing dip of the sediments is 20°–30° NW. Underground workings, unlike the surface exposures, reveal considerable calcareous sediment.

Traversing this general country rock in a northeasterly direction about 135 feet north of the shaft are croppings of quartzite breccia stained with limonite. This material has been traced for some distance on the surface and is cut by the shaft about 250 feet down. It was this mineralized breccia zone that determined the location and development of the property. The workings cut some quartzite and some silicified limestone, but contrary to what would be expected from surface indications they are mainly in metamorphic limestone. Thus the 400-foot station and the north drift are entirely in marble; the northeast drift is in marble; and the southwest and southerly drifts are in marble until near their faces they enter quartzite. The dip near the 400-foot station is 35° NW.

The three systems of fractures did not disclose intersections which conclusively proved their relative age. The most important system was clearly that trending northeast and southwest. It was evident in one place that the intrusive is earlier than a northeast fissure.

The principal occurrence of ore noted was along a northeast fissure zone which dips southeastward. From the point where it was cut on the 400-foot level, about 50 feet south of the shaft, it has been opened laterally for several hundred feet. At the northeast it has been opened vertically above and below this level and at a point about south of the shaft has been followed down for about 300 feet. Good ore occurs in this zone through a width of 3 to 4 feet in seams or bands 6 to 20 inches wide and in winzes. Both walls were limestone 100 feet below the 400-foot level at the winze, also at the 600-foot level, where the limestone is fresh and blue or black. The trend holds fairly constant, being on the 500-foot level N. 65°–75° E. and on the 600-foot N. 55°–60° E., with the downthrow on the southeast.

The ore left in the walls of the stope on the 400-foot level showed galena and pyrite with considerable carbonate. Eight inches of solid sulphide ore with carbonate outside occurred 170 feet below, and on the 600-foot level an 8-inch vein showed galena, gray copper, and azurite. Ore of this character in a somewhat stronger vein is reported to have persisted downward as far as opened, at least for 760 feet.

The ore shipped has yielded lead, silver, copper, and gold. Apparently the earlier shipments gave more copper, and those from the 760-foot level gave gold. Thus the shipment from that depth made late in 1906 showed 109 to 131 ounces of silver to the ton, 12 to 20 per cent of lead, and $1 a ton in gold.

CONSTELLATION GROUP.

The Constellation group occupies the spur between Ontario Canyon and Frog Valley. The shaft is on the crest of the lower shoulder of the spur and the tunnel workings enter the eastern slope. Work has proceeded on the Constellation group and on adjoining leased claims for several years and has effected considerable development of virgin ground. The shaft was begun about 1895, but the tunnel workings are a continuation of one on the old Le Compte claims. The Constellation property has been developed to a depth of 200 feet by a one-compartment shaft from which spring two levels at 100-foot intervals. The upper level is merely an adit 100 feet long to the west, but the main level is a north-south crosscut 1,400 feet long with lateral drifts to the west, chiefly south of the shaft, which aggregate about 700 feet. Of the tunnels on the leased land at the east, the main one reaching the property of the Constellation Co. enters from Frog Valley and crosscuts in a nearly westerly direction for about 700 feet. At 500 feet from the entrance a north-south drift 400 feet in length affords entrance to two short terminating crosscuts parallel with the main tunnel.

The country rock in the vicinity is chiefly Weber quartzite intercalated with layers of limestone and cut by a dike of diorite porphyry on the west slope of Frog Valley. Float and gravels are prevalent on the ridge about the shaft, but rock in place occurs abundantly north and south of the shaft as well as on the slope north of the main tunnel. At these points quartzite is the only rock observed except some porphyry at the mouths of prospects. Its craggy ledges are generally whitish to brownish and in spots exhibit, perhaps as a result of sedimentation, alternate white and brown bands. The several outcrops indicate complicated structure; for north of the shaft the dip is about 15° NW., but to the southeast it is 10° NE. and north of the tunnel 15°–25° SE. The quartzite is somewhat jointed, but, except for a few fissures of small proportions and generally northeast trend, surface evidences of deformation are limited to zones of brecciation in the quartzite. These occur on the slope north of the tunnel and on the north face of Bald Mountain and, though difficult to follow, appear to extend in north-south lines. Underground the same rocks occur, and the softer calcareous members as well as the deformation and structure may be more easily studied. In the first 100 feet the shaft cuts waterworn gravels containing abundant pebbles of quartzite and porphyry. Thence downward the shaft penetrates quartzite, as does also the entire 200-foot level except for two narrow bands of impure shaly to sandy limestones. One of these is midway of its northern extension and the other parallel with the main lateral drift. Such dips as were observed were uniformly to the south-

east at angles of about 40°. The rocks have suffered considerable sheeting, though only slight fissuring, along north-south lines, but the main deformation occurs as probably later northeast fissures uniformly vertical or dipping northwestward and having some indications of downthrows on the northwest. A few traverse the level north of the shaft, but the most important are those which have been followed by the lateral drifts south of the shaft. These comprise two main fissures, one on the main drift and another to the southeast opened by the back drift. They both extend southeastward and inclose a much decomposed brecciated fault block of impure limestone, whose dip it was impossible to obtain. The relative movements of the rocks on these fissures appear to have been diagonal on the fault plane, for slickensides dip 70°–80° SW. There has also been considerable slipping on bedding planes, apparently in an east-west direction.

The same rocks with a small amount of porphyry appear in the tunnel. The porphyry occurs at the mouth of the tunnel and continues for a distance of 200 feet, the contact lying against a blue decomposed limestone. The limestone is a band about 50 feet wide and represents part of a layer intercalated in the Weber quartzite, but here it is truncated by a fissure and abuts the quartzite. The country rock of all the remaining workings is quartzite, except possibly some fragments of limestone in the fissure breccia of the south crosscut.

The deformation has so thoroughly crushed the rocks that little if any structure can be definitely made out. Only two dips were observed, one in the limestone being 45° N. 68° E., and another at the face of the main tunnel being nearly due west; but this apparently anticlinal structure may have been induced by faulting. The sediments are extensively and thoroughly broken by manifold fissuring, whereas the porphyry seems to be less disturbed. Nearly all the fissures may be included in the northeast quadrant, but those approaching the north-south line appear to be older than the northeast or east-west systems. Three main fissures were found. One lying near the portal and between the limestone block and the quartzite trends generally northward and displays 4 feet of breccia. It dips to the east and, to judge from the increased inclination of the neighboring limestone, the movement may have been relatively down on the east. Another fissure not over 2 feet wide follows the south crosscut and dips northward, but it is interesting structurally only in containing fragments of limestone, which were perhaps dragged in from above or below, and in offsetting the north-south system of slight fissures on the main drift. The largest fissure was observed near the face of the main tunnel and because of its northeast direction the workings to the north intersect it twice. The breccia zone is 15 feet wide, dips 60° NW., and is evidence of considerable movement, the amount of which, however, can not be made out in the homogeneous quartzite.

The croppings of anything which would encourage a miner are confined to the brown iron-stained breccia zones above noted, in the quartzite ledges. Such indications of mineralization are not visible at the shaft because of the mantle of gravels, but they occur east of it not far from the tunnel and generally on the ridge north and south of the workings. Attending these zones are sporadic slickensided fissure planes which appear in several outcrops, but they seem entirely barren. Underground the material looks more promising, but no commercial ore was seen and indications of minerals are found most abundantly near the fissures. In the tunnel all the fissures bear red and black stains of the iron oxides and the vein matter of those on the north and south crosscuts is reported to assay $3 to the ton in silver. The quartzite is in places inclined to be cavernous and the small recesses in it hold black stringy material and quartz crystals and show iron stains. Midway of the main tunnels pockets of carbonate ore are said to have been discovered.

In the shaft likewise indications of ore are limited to iron-stained fissures. The chief mineralized area was along the fissures of the lateral drifts. The northern fissure was considerably stained with oxides of iron and manganese, and it was here also that nodules of galena 2 to 3 inches in diameter were said to have been taken from the gouge of the fissure. These nodules as shown to the writer were somewhat carbonated on the surface and may have been dragged into the fissure from a considerable depth. In the fissure along the back drift mineralization is shown chiefly by some bright-red chalky material similar to that found in the south drift of the tunnel. This material appears to be merely pulverized and decomposed rocks satu-

rated with red oxides of iron (?). Nonmetallic mineralization is limited to calcite and quartz fissure veins that show evidence of being crushed by recent rock movements.

Thus mineralization is confined chiefly to the smaller fissures, though the agents seem to have corroded the walls also, especially in the tunnel. The resulting minerals are chiefly oxides of iron and manganese, with quartz and calcite. In addition small amounts of argentiferous minerals assaying $3 of silver to the ton are reported from the tunnel and galena nodules from the shaft workings.

EMPIRE CANYON.

GEOLOGIC FEATURES.

The general features of Empire Canyon and the particulars regarding the part lying within the limits of the Ontario fissure system have been described under "Ontario and Empire canyons" (pp. 134–136). It remains to supplement these descriptions with information on certain features outside of the fissure zone which may aid in understanding the detailed descriptions of the remaining mines in this canyon.

Starting in three heads on the main eastern divide, at Little Bell, Sawtooth, and Daly Judge gaps, with flaring cirques at the first two, the canyon descends steeply northeastward between narrowing walls which just above the mouth of Walker & Webster Gulch close to form a pass. Beyond it falls steadily between high, steep ledgy slopes and unites at Park City with its neighbors.

This course runs through most varied stratigraphic and structural features. Empire Canyon roughly marks the boundary between the Weber quartzite on the east and the limestone and shale formations on the west. But this simplicity has been so thoroughly destroyed by intrusion and faulting that this region is one of the most complex in the entire district. In the normal succession the Park City formation on the Quincy spur overlies the Weber quartzite, the Woodside shale on the west side of the same spur overlies the Park City and is in turn stratigraphically under the Thaynes formation along the main divide, in Sawtooth Peak and to the west, and similarly downstream to the north opposite the Daly shafts this same succession appears overlying the quartzite, yet this general succession is in places greatly modified by intrusion and faulting. The quartzite making Flagstaff Mountain has been cut by a body of diorite porphyry, and a dike from this mass extends westerly toward the Quincy. The dike is topographically indicated by an exceptionally distinct erosion gully. On the Quincy spur, in line with this dike and just south of the Quincy shaft, a narrow dike outcrops, and capping this spur is an extensive mass of diorite porphyry, probably roughly in the form of a sheet. Beyond, in Daly-Judge (Anchor) Gap, the Clayton Peak mass of diorite extends northeastward about 1,000 feet. Just northeast of the Daly-Judge shaft a vertical dike of coarse diorite porphyry crosses the spur and disappears beneath the ground moraine which floors Morgan Gully, though a similar dike crops out amid the glacial débris just west of the Daly West shaft. A small sill outcrops immediately south of the Massachusetts shaft.

Furthermore, this sedimentary succession thus intruded has been modified by much complex faulting. The contact between the Weber quartzite and the limestone of the Park City formation east of the Little Bell and Quincy shafts and west of the Mazeppa shaft appears to be a fault which is followed by the bottom of the gulch, on which the limestone of the west side has been dropped several hundred feet. The next gulch west, between Landmark Peak and Sawtooth Peak, is on crumpled, highly disturbed metamorphic shale and probably follows a fault zone which caused an apparent thinning of the shale. The part of the divide on the west between this gully and Anchor Gap, consisting of metamorphic limestone of the Thaynes formation, appears to be cut up into blocks by a series of parallel northeast-southwest faults. Next west and doubtless marked by Anchor Gap is the probable position of the master fault zone of the region—the Daly-Daly West-Daly-Judge fissure system. This appears to be indicated topographically by the decided offset of the main divide toward the south on its east side and by the main valley extending from this gap northeastward by the Daly-Judge and Daly West shafts. In the downthrown hanging wall of this great zone west of the Daly shafts the formations have

been deformed by east-west faults on which the northern member is uniformly offset to the west. Two great fault zones end this series at the north—the Crescent zone and the Massachusetts zone. On the former the limestone of the Thaynes formation, which rises along the west side of Empire Canyon, terminates at the north and is displaced about 5,000 feet to the west, reappearing in Crescent ridge. On the latter, which is marked by and named from the Massachusetts shaft, the contact between the Park City formation and the Weber quartzite is relatively offset about 2,500 feet to the west on the north side. The details of all these faults are given in connection with the descriptions of the mines in which they are best developed.

Finally, the location on the surface of the features produced by these deformational movements were effectually hidden by heavy deposits of mixed soil and bowlders laid over the bottom and sides of this canyon by ice. The hummocky kettle moraines at the middle head gulch, the lateral moraine on the west side of the canyon between the Daly-Judge and Daly West shafts, the perfectly developed double frontal moraine inclosing Morgan Hollow and holding up the Lady Morgan Lakes, the ground moraine which covers much of the valley bottom in this upper section and below stretches continuously from the Daly No. 2 shaft across Empire Canyon and Walker & Webster Gulch to Woodside Gulch, and other features of the latest epoch of geologic history are described in detail under "Glacial deposits" (pp. 60–62).

In a region where such formations have been so intensely affected by fracturing and intrusion it is not surprising that large bodies of rich ore were formed. The prevailing modes of occurrence were as lode ores and as replacement beds adjacent to fissures.

AMERICAN FLAG MINE.

SITUATION AND HISTORY.

The American Flag mine is situated on the east side of Empire Canyon about seven-tenths of a mile south-southwest of its junction with Woodside Gulch at Park City, half a mile northeast of the mouths of the Daly-Judge and Alliance tunnels.

The property comprises a group of patented claims that occupy all of the area, excepting the Ontario tunnel, etc., between the Alliance and Constellation, Daly-Judge, and Ontario properties, a total of 136 acres. The principal claims that formed the nucleus of this group were those embraced in the old Thunderer property, which was formerly opened and developed by William Curtis and John G. Rhodin. In 1900 this group was purchased from Curtis, and gradually other claims were added, including the Centennial and Prince Oscar (among the earlier claims in camp), the Queen Stope, and the Flaxton-Sweden. Late in 1902 this consolidation was organized as the American Flag Co. It is understood that the basis of selection in gathering the claims consisted of certain lodes that had been revealed in the course of work in the Thunderer, and the belief that other good lodes existed in the quartzite in the hanging wall of the Ontario lode. Up to that time no work had been done outside of the Thunderer except for patenting, and the only shipments were those from the Thunderer.

On the formation of the new company a campaign of development was quietly but energetically begun. By December, 1903, the American Flag shaft had been sunk to a depth of 850 feet and drifts had been turned and run for long distances. During the next year development was continued and at the time of the writer's last visit (November, 1904) the shaft had reached a point 1,120 feet below the collar. Up to that date 250 tons of ore had been shipped.

DEVELOPMENT.

Two groups of workings have been opened in the American Flag ground, that in the old Thunderer mine and that comprising the recent American Flag shaft and connected levels. This shaft is 1,400 or 1,500 feet northeast of the mouth of the Daly-Judge tunnel, at about the same elevation, or about 150 feet above the canyon bottom. It has two compartments and a manway. Levels were turned at depths of 500, 600, 700, 1,000, and 1,100 feet, and drifts were run exploring veins on those levels. The old Thunderer workings comprise a tunnel extending about 500 feet in a southeasterly direction, a winze which descends at an angle of 65° SW. 300 feet on the incline, with two small levels running off at 30 and 135 feet, and a main lower level at the foot extending in a northeast-southwest direction about 300 feet.

Country rock.—These workings lie within the great central area of Weber quartzite uncovered along the axis of the Park City anticline and in the hanging wall of the Ontario lode. The outcrops in this locality show massive Weber quartzite dipping north-northwest on the west side of the area, lying very flat in the central part and dipping 20° N. 41° E. on the east side of Ontario Gulch, toward the Constellation mine. The divide between Ontario and Empire canyons, in which the workings lie, is heavily blanketed with glacial débris, including large blocks of quartzite, limestone of the Thaynes formation, red shale, and porphyry. About 1,000 feet east-southeast of the American Flag shaft, in the same spur, is an area of diorite porphyry. In Empire Canyon just above the reservoirs calcareous beds are intercalated in the massive quartzite, and similar beds have been cut in the underground workings from the American Flag shaft. Aside from these small exceptions the country rock is the massive Weber quartzite. This flat arch of quartzite, pitching gently northward and cut by porphyry, is broken chiefly along northeasterly but somewhat also along northwesterly directions and doubtless considerably faulted.

Ore bodies.—The workings from the shaft have developed a strong lode in quartzite that outcrops just southeast of the shaft and has also been opened by two small prospects north of the shaft and by the lower tunnel. It descends, with a rolling dip toward the southeast ranging from 63° to 80° and a strike ranging from N. 30° E. to N. 45° E., for at least 1,000 feet. From the 500-foot to the 700-foot level the shaft lies in this well-defined fracture zone. Its walls are Weber quartzite with some small exceptions, as on the 1,000-foot level north and northeast of the shaft, where limestone appears in the hanging wall.

The general crushed zone comprises bands of finely and coarsely broken material, with some sharp slips and bands of stained crushed country rock. The stains consist mainly of iron or manganese, and in many places lead to and apparently are associated with good ore.

The ore bodies occur within this zone of fracturing and crushing in roughly tabular form, and are generally parallel in trend and dip with the main zone. They are made up of bands from an inch to a foot in width, composed of stained and some ocherous material. At the time of the writer's visits the work done on the 500, 700, and 1,000 foot levels was inadequate to reveal any localization of the bands to form a shoot. Beyond doubt there is a shoot, though its length along the strike, its pitch, and its persistency in depth remained to be shown in the course of mining operations.

The material that is mined as ore in the main lode is unlike the run of ore in this district in that it does not reveal to the eye its metallic contents. Lean-looking quartz breccia and rusty ocherous or manganiferous parts of the vein yield metals on assay. In general the ore is made up of angular fragments of quartzite and massive and crystalline quartz cemented by manganiferous and ferruginous matter. Areas of soft decomposed mineral occur which suggest an altered porphyry, but the evidence at hand is insufficient to permit definite conclusion. Some of the vein material from the lower level of the Thunderer workings is clearly associated with porphyry. One sample from the 1,000-foot level of the main mine shows galena and some tetrahedrite in a siliceous gangue.

The ore in these stained oxidized bands is of particular interest in that assaying alone reveals its tenor and that this is unusually high. Some of the figures given out by the managers in the early stages of the development of this property indicated such high contents in gold and silver that they would have been difficult to believe had they come from any less reliable source. The writer collected some fair-grade samples of the various types of vein matter on the 1,000-foot level that were regarded as ore. Three of these taken at random and a picked sample of rich ore yielded the following results on being assayed:

Assays of ores from American Flag mine.

	1	2	3	4
Gold, ounces per ton..	0.08	0.04	0.01	1.52
Silver.....do....	3.85	11.0	2–6	478.9
Lead.....per cent..	4.0	2.1	.0	26.6
Copper.....do....	.9	.15	.15	5.23

1, 2, 3, Random samples; 4, picked sample of rich ore.

At the time of the writer's last visit small regular shipments were contemplated and a method of treatment expected to save all the metals was being considered. In general it was stated by the manager that gold was higher in the upper levels than in the lower, and higher than silver in the upper levels; and that silver was higher than gold in the lower levels.

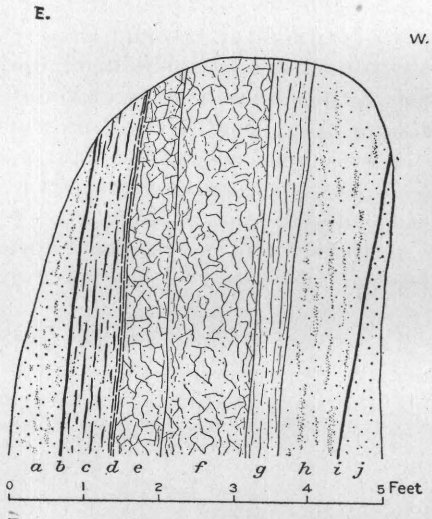


FIGURE 18.—Sketch showing structure of fracture zone, Thunderer tunnel, bottom level, American Flag mine. *a*, Quartzite with iron stains; *b*, hanging-wall fissure; *c*, ferruginous gouge; *d*, clay; *e*, *f*, brecciated quartzite; *g*, limonitic material; *h*, quartzite with iron stains; *i*, footwall fissure, iron and manganese stains; *j*, sandstone.

In the old Thunderer workings the mode of occurrence of the ore is not so distinct and uniform as in the main mine. A system of northeast fissures and two bodies of porphyry were cut, and a good fissure zone, which was opened on the upper (tunnel) level, followed down an incline, and developed at this bottom level in both directions along its strike, is stated to have yielded gold and silver ore of very high grade (fig. 18). The ore is in general like that from the main mine, and the manager was of the opinion that this vein and the main lode opened through the American Flag shaft are the same.

FRIGE TUNNEL.

The Frige tunnel is located on the northwest side of Empire Canyon immediately below the Daly-Judge mill and opposite the American Flag shaft. It is reported to be an old tunnel driven southwestward about 1,200 feet to catch the Fairview fissure. It was subsequently purchased by the Silver King Co. as a work tunnel for use in exploring its ground, before the Alliance tunnel was obtained. At the time of visit the tunnel was caved and wholly inaccessible. Its entrance is in the upper part of the Weber quartzite and the dump so far as seen showed only quartzite, the object of the tunnel being to crosscut that formation near the top.

MASSACHUSETTS SHAFT.

The Massachusetts mine, at the south side of the junction of Walker & Webster Gulch with Empire Canyon, is now included in the holdings of the Silver King Coalition Co., and the general features of its geography, geology, etc., are covered by the sketch of that property (pp. 178–188). The main shaft was sunk in the late seventies and early eighties and stoping is reported to have been done in 1880 on the 100, 200, and 300 foot levels. The first period of its history, in which some ore had been struck on the 200-foot level and work had been carried on irregularly, was ended in 1887 by reorganization. The Empire Mining Co., which had owned the property, then dissolved, and under the name Massachusetts a new company began sinking from the 400-foot level an enlarged shaft of three compartments, reaching the 500-foot level in December. The next year the shaft was sunk another hundred feet and exploration was carried on at that level, but in December, after being in operation for 14 months, the mine was closed. In March, 1891, the mine was placed under new management and in May was again opened, but was closed in July. The early development was hindered by water, which was later drained by the deeper drain tunnels of the large companies. After the unsuccessful attempts to operate the property it passed into and has since remained in the possession of the Silver King Coalition Mining Co.

The workings, which are entirely inaccessible, comprise the Massachusetts shaft, which is reported to have been sunk 600 feet, and levels at depths of 200, 300, 400, and 600 feet. It was stated to the writer by a former operator of the property that on the 200-foot level considerable work was done, on the 300-foot level a long drift was driven southeastward, on the 400-foot level several hundred feet of work was done to the west, and on the 600-foot level a drift was driven toward the Fairview incline for about 700 feet.

It appears at the surface, and this appearance is substantiated by reports that the shaft was sunk on a strong northwest-southeast fault, which is consequently known as the Massachusetts fault. The great downthrow on the south side of this fault and the relative displacement of the

southern member to the east are described in detail under "Structure" (p. 95), also in the section on the Silver King mine (p. 183). The zone is cut by the Daly-Judge tunnel, and has been opened through the Alliance tunnel at that level in both directions, along its strike at a deeper level, and in the Silver King mine. These workings, which, it is understood, were practically all in quartzite, have developed seams and bunches at a few places but, so far as known, no important well-defined shoot. In the old workings from the shaft, it is reported, ore was first encountered on the 200-foot level, a 6-inch band was opened on the 300-foot level, and between the 400 and 500 foot levels, about 500 feet south of the shaft, a seam of mixed sulphide and carbonate of lead dipping northward widens from 6 inches to 2½ feet. For all the work that has been done on this zone, early and late, it apparently has yielded no adequate return.

DIAMOND-NEMROD PROPERTY.

The Diamond-Nemrod ground lies across the ridge between Empire Canyon and Walker & Webster Gulch, north of the Daly West and Daly-Judge properties. It comprises the former West Ontario group, which extends into Walker & Webster Gulch, and the Black Diamond and Nemrod claims, in Empire Canyon. In 1885 and 1886 work was done on the two last-named claims and some ore was found. The West Ontario had been prospected by a long tunnel and a shallow shaft, and it was reported that a vein of carbonate lead ore was struck. In 1903 the properties were consolidated and reorganized in Colorado as the Diamond-Nemrod Co. Late that fall work was started with the avowed intention of exploring for certain fissures previously found in this ground. A shaft was sunk, which at the time of visit late in 1904, had attained a depth of 815 feet, and the face of a drift driven N. 60° W. was then 70 feet from the shaft.

The ground of this group includes limestone of the Thaynes formation and considerable red shale (Woodside). The workings in the spur northwest of the Daly West shaft lie in the base of the Thaynes and the upper part of the Woodside shale. Thus the shaft descends through 200 feet of red shale, 500 feet of calcareous gray beds, and 100 feet of red shale. The drift off the foot of the shaft cuts red shale and pinkish limestone which strikes N. 60°, 70°, and 80° W. and dips 22°, 28°, and near its face 32° SW. It is reliably reported that some ore was found in a fissure cut by an old incline driven high on the spur in early days, but no indication of ore exposed by recent workings was observed.

LITTLE BELL MINE.

SITUATION AND HISTORY.

The Little Bell mine is situated at the head of Empire Canyon on the west side of its eastern head fork, about 700 feet south of the Quincy shaft and about 1,700 feet south-southeast of the Daly West shaft.

This property was located August 17, 1880. A tunnel was driven from the creek level, but no systematic development was carried on until 1901. About that time the extraordinary ore developments in the Daly West mine and the strikes of rich ore in the Quincy led to vigorous efforts to establish and to secure the apex or apexes of these bodies of rich ore. The Little Bell shaft was started (August, 1901) and some lateral exploration was done. It was understood that a control in this property was acquired by owners of the Daly West mine. After this period of development, which yielded only fair results, operations dwindled to irregular prospecting. In 1906 extensive exploration toward the west exposed a considerable body of rich lead ore in the lower part of the limestone above the Weber quartzite. Again in 1909–10 the discovery of a large body of ore was reported and valuable shipments indicated its importance.

DEVELOPMENT.

The development in this ground comprised at the time of visit the old surface tunnel extending 200 feet southwestward from the creek level; and the shaft, 753 feet deep, with levels turned from it at depths of 100, 200, 300, and 500 feet. The 100-foot level carried 200 feet south from the shaft, the 200-foot level with about 400 feet of work done on the north and northwest side of the shaft, and the 300-foot level with about 900 feet of work south of the shaft all together

fall several hundred feet short of equaling the extent of work on the 500-foot level to the north, west, and southwest of the shaft. There were also stations on the 600 and 700 foot levels. Since the date of visit considerable development work has been performed, some of which has recently resulted very successfully. On the 300-foot level of this mine and the 200-foot of the Quincy these mines are connected.

ECONOMIC GEOLOGY.

The Little Bell mine has been opened in the lower third of the Park City formation and the highest part of the Weber quartzite. The general dip of these formations is 20°–30° N. 45°–55° W. The tunnel and the 100, 200, and 300 foot levels lie in the gray carbonaceous and cherty calcareous beds characteristic of the basal members of the great bonanza-bearing formation of this district. The workings below the 300-foot level are in massive homogeneous Weber quartzite, except for some limestone that is doubtless intercalated cut in the shaft at the 700-foot level.

The sedimentary beds are cut at the several levels by fracture zones which trend northeast-southwest and east-west. The prevailing inclination of slickensides on the 500-foot level is 30°–34° W.

The Little Bell ground lies between the ore-bearing fracture zones and bonanza-bearing beds of the Daly West and Quincy properties on the north and extensive masses of diorite and diorite porphyry on the south. Within the limits of this property the geologic requirements for each of the two types of ore found in the adjoining ground to the north are proved to exist. At the time of visit the crucial question among parties interested in the region was whether the Daly West ore-bearing beds continued upward (southeastward) on the dip into Little Bell ground. Clearly the lower part (280 feet) of the Park City formation, which descends through this ground, should embrace any ore-bearing member that would extend upward in its normal position of 30 to 40 feet above the Weber quartzite. Whether the same or an equivalent bed does persist in this ground was at the time of visit not demonstrated by accessible development.

On the 200-foot level west, in the general calcareous formation, a 2 to 6 inch band of barren gouge is underlain by a 2-foot brown sandy member, which the operators regard as equivalent to the sandy member that forms the footwall for the replacement bodies in the Daly West mine. Neither the stratigraphic succession at this point nor the exact position of these beds with reference to the top of the Weber quartzite could be made out from the meager exposures by present development, so that the identification of the desirable members in this ground was then impracticable. No ore replacing any of the sedimentary members had been found at the time of latest information.

Fractures have been found, however, which carry good ore between the limestone and quartzite walls. Three main zones trending east-west and dipping north have been opened on the lower levels. The northern zone has been followed on the 500-foot level east and west from the station. Although showing good sheeting and crushing and some staining, it yielded no ore. The middle zone has been opened on the 300-foot level for several hundred feet and on the 500-foot level for about 300 feet. It lies about 250 feet south of the shaft, trends in a general east-west direction, and stands nearly vertical (78°–90°). On the 300-foot level, between a limestone hanging wall and a quartzite footwall, it showed considerable manganese and in a branch running northeast some bunches of rich secondary ore. On the 500-foot level apparently the same general zone in quartzite showed crushed iron-stained quartzite 3 to 4 feet in width with one to three seams of oxidized ore 6 to 8 inches wide. The southern zone, opened on the 300-foot level and possibly connecting with the other on the 500-foot level, is a highly manganiferous breccia zone 3 feet wide between a limestone hanging wall and a quartzite footwall (the latter on the south), without ore, however. It appears that narrow seams of ore formed in east-west cracks and that on subsequent movement these were broken, crushed, and left in isolated lenses or bunches, in which the copper has been enriched on the 300-foot level to oxide and silicate and the lead below has been changed to less degree, forming sulphate and carbonate. The principal ore minerals observed were galena, anglesite, cerusite, chrysocolla, and cuprite. These occurred in bunches, which yielded small amounts of rich ore. Recently it is reported that excellent ore has been struck in considerable quantity.

LUCKY BILL SHAFT.

The Lucky Bill property is situated on Flagstaff Mountain at the head of the southeast fork of Empire Canyon, about 2,500 feet southeast of Little Bell shaft. It was located early in the prospecting of the vicinity of Flagstaff Mountain and the ground was actively explored in the middle eighties. By 1888 its tunnel was in 775 feet and its shaft down 75 feet. The tunnel, which was at the same depth as the 200-foot level of the shaft, was subsequently connected with the shaft by a crosscut. In February, 1892, it was reported a vein was struck from the shaft at a depth of 300 feet. A year later an assessment was levied, and although it is understood that considerable more work was done both in the tunnel and the shaft, apparently no ore of much value was found, as in 1895 the assessments had reached No. 15. A map of the underground workings shows a 200-foot level extending about 250 feet northeast from the shaft, a 300 foot extending 150 feet northeast, a 500 foot extending about 350 feet northwest, and a 1,000 foot with about 500 feet of work done south of the shaft.

In this area the prevailing country rock, Weber quartzite, is invaded by diorite porphyry and both of these rocks have been considerably fractured and fissured. The finding of some rich ore has been reported, but no noteworthy occurrences of ore on the property are known to the writer. In 1901–2, when the question of the apex and ownership of the bonanzas in the Daly West and Quincy mines was arousing the keenest speculation, it was held by some that the apex was in the high ground on the south, in this vicinity. As this view found no basis in geologic structure, however, the activity thus stimulated speedily diminished, and so far as known the property has since lain dormant.

FLAGSTAFF SHAFT.

The Flagstaff property is situated along the top of Flagstaff Mountain between the heads of Ontario and Empire canyons, next east of the Little Bell and Lucky Bill properties. It was located May 30, 1871, by James M. Kennedy. Early owners have stated that ore discovered on the property that year was the second found in the camp. The first ore shipment from the Park City district was made from this ground in July, 1871, and the following year additional shipments were made to an Ogden smelter. After changing hands several times the property was bought in 1873 for $50,000, by the Marsac Co., which erected a 20-stamp mill in the summer of 1874 to treat Flagstaff ores. The property appears to have continued active for several years and considerable work was done in spite of serious physical obstacles. As late as 1881 it is recorded that 5 tons of ore were shipped which assayed $60.

Fractures in quartzite near intrusives showed some mineralization. In one place considerable barite was found distributed in stellate aggregates on the walls of a fissure. It is stated that the first ore discovered occurred as a 10-inch vein of oxidized lead-silver ore striking northeast-southwest and dipping northwest in quartzite. The early development comprised an incline sunk on this vein for 400 feet. After the ore that afforded the early shipments, which apparently lay only near the surface, was exhausted, similar incline and shaft were sunk nearby. So far as learned, however, no more ore was found. In recent years no active work has been done on the property.

WALKER & WEBSTER GULCH.

GEOLOGIC FEATURES.

Walker & Webster Gulch lies between Empire Canyon on the east and Woodside Gulch on the west and extends southwestward roughly along the probable strike of the bedrock. Its bottom throughout its length is floored with glacial material which effectually blankets the underlying rock formations. From exposures along the inclosing slopes and divides, however, it is seen that the gulch probably lies in limestone of the Thaynes formation and Ankareh shale except at the mouth, where limestone of the Park City formation and the Weber quartzite appear. The prevailing dip is 30°–40° NW.

The normal character, distribution, and structure of the formations are modified by contact metamorphism and by profound faulting. In general the formations are metamorphosed at

the southwest to marble, argillites, etc. These rocks stand up in bold ledges along the high master divides, which adjoin and surmount an extensive intrusive mass beyond on the south. They are distributed, so far as may be seen from the portions not covered with drift, in roughly parallel outcropping zones trending northeast and southwest. The highest formation (Ankareh shale) lies at the extreme west in Pioneer Ridge, at the head of the gulch, and is underlain by the Thaynes formation in Crescent Ridge, about the head of the gulch in Jupiter Hill, and to the east in Morgan Knob. At the north, about the mouth of the gulch, the Park City formation and underlying Weber quartzite occur.

The distribution of these formations as broadly sketched above is modified materially by profound faulting. The more important faults that have been observed fall into two main zones, the Massachusetts and the Crescent fault zones. The former extends through the Massachusetts shaft and northwestward across the mouth of Walker & Webster Gulch. Broadly, the surface features indicate a total horizontal offset of approximately 2,500 feet toward the west on the north side. The Crescent zone extends west-southwest across this gulch a short distance south of the mouth of the Hanauer tunnel and crosses Crescent Ridge at its junction with Pioneer Ridge in the vicinity of United States land monument No. 4. Its effect is to offset the Thaynes formation from the west side of Empire Canyon to Crescent Ridge, about 3,000 feet on the north side of this zone. About 1,000 feet southwest of this zone a similar and roughly parallel zone of apparently less geologic and economic importance crosses Pioneer Ridge. These constitute the principal deformations in this locality, although other faults of various trends are found. The details of these major features and the more noteworthy minor points are given in connection with the descriptions of the several properties lying in Walker & Webster and Woodside gulches.

The ore bodies thus far found in this locality occur as lodes or as lenticular replacement bodies adjacent to the lodes.

KEARNS-KEITH MINE.

SITUATION AND HISTORY.

The Kearns-Keith mine lies in Walker & Webster Gulch, extending from the mouth up to the junction of Crescent and Pioneer ridges. One adit, the Alliance tunnel, is at the mouth of the gulch just above its junction with Empire Canyon, and another, the Hanauer tunnel, about 500 feet to the south-southwest.

The Kearns-Keith property comprises a group of mines which were opened in the earliest days of the camp, operated through the eighties, and gradually waned in the early nineties. They include the Walker & Webster Apex, Sampson, Rebellion, Climax, Piñon, Buckeye, Boss, and others. The history of the present Kearns-Keith property is the history of the development of these several small mines and their consolidation into a few larger properties, then into this one. In 1869 the Walker & Webster claims were located by Rufus Walker and ore was struck on them by Ephraim Hanks. In 1870, two years before the discovery of the Ontario and 19 years before the discovery of the Silver King, the Green Monster, Piñon, and Buckeye claims were located along the crest of Pioneer (formerly known as Piñon) Ridge. Ore was shipped from the Piñon and the Walker & Webster from the outset up to 1875 to Grabe's smelter at Rush Lake. A lull followed until, in 1880, the Rebellion and Climax mines struck ore on the northwest side of the ridge, and these finds aroused prospectors to great activity in locating neighboring ground. Previously the ore had been found along fractures, but work in the Piñon mine led to exploring for ore in beds and to the location of ground on the north side of Pioneer Ridge, believed to embrace an apex of bedded ore. In working out the relations of these occurrences questions of ownership led to litigation regarding the Piñon-Climax ore bodies, and later, in 1886–87, similar questions arose regarding ore in crosscut Sampson-Boss ground. In 1882 the Climax-Rebellion apex suit was settled by the consolidation of the Climax, Rebellion, Piñon, Walker, and Buckeye mines under the name Crescent. The following year the Crescent Co. declared its first dividend, amounting to $150,000. In the next year it erected the first concentrator in camp, which was improved and enlarged in 1886. During the latter year this mine ranked second in production

in the Park City district and through 1889–90 it held fourth place. After declaring its seventh dividend in 1888 the company closed the mine in 1891. Meanwhile new producers were developed—the Sampson and Apex in 1883 and the Boss in 1885. The Apex declared a dividend in 1888; but the Sampson, which had a good outlook for ore in its early days, encountered various difficulties, and in 1888 was closed and sold under mortgage. It was reorganized in 1889 as the Alliance, and the deep Alliance drain tunnel was started on August 17 of the following year and completed with a total length of 4,590 feet. During the early nineties activity among these properties gradually slackened. The Crescent resumed in 1893, was idle in 1894, and levied an assessment in 1895; the Alliance was shipping in 1892; litigation arose in 1895 between the Crescent and Silver King over water rights and in 1896 between the Alliance and Silver King, the latter suit terminating three years later in the purchase of the Alliance by the Silver King for $65,000. For the next few years little was done on these properties beyond some shipping of concentrates from the Apex and advancing the Alliance tunnel. In 1903 all these mines, including the old Walker & Webster and the several properties on the west covering Pioneer and Crescent ridges, were consolidated under the name of Kearns-Keith. Restoring the early workings and new development through the Hanauer tunnel were aggressively taken up, a modern plant was established at the mouth of that tunnel, and exploration was carried on through the Alliance tunnel. The ore taken out was treated in a newly erected mill on the property and the concentrates were shipped to the valley smelters. The following description applies to this group of mines at that time. In 1908 it was reported that the property had been acquired by the Silver King Coalition Co. The total production of this ground to date could not be ascertained. The total dividends paid by the Crescent were stated in 1899 to amount to $280,000.

PLANT.

The plant of the Kearns-Keith Co. includes a 100-ton mill with the usual shops, assay office, and living quarters, all located in Walker & Webster Gulch, at the mouth of the Hanauer tunnel. The mill is a duplicate of one unit of the Silver King mill. It was built in 1903 and went into commission in December of that year. Its equipment includes 1 Gates crusher, 2 Davis rolls, 8 Hartz jigs, 2 Huntingdon mills, 1 classifier, 6 Wilfley tables, and a Wilfley slime table. The degree of concentration is 5 and 6 into 1. At the time of visit a lead concentrate was produced without making any middling or saving zinc. Power was transmitted by compressed air which was piped from the plant at the collar of the Silver King shaft, through that mine, up the King-Alliance raise, through the Alliance crosscut, and throughout the Alliance workings.

DEVELOPMENT.

The principal ore zone has been entered through five long tunnels and opened for a distance of about 1,500 feet and a width of 300 feet at a dozen levels. The bulk of the mine workings lie in this northeast-southwest zone 500 to 1,500 feet south and southwest of United States land monument No. 4. From the east the deep drain tunnel, the Alliance (elevation 817 feet), extends from the mouth of Walker & Webster Gulch about 7,200 feet west-southwest to the foot (elevation 860 feet) of the inclined raise to the main mine workings 750 feet above. The main work tunnel, the Hanauer (elevation 1,600 feet), extends from the basin in central Walker & Webster Gulch 2,000 feet west-southwest to the main crosscut incline, and thence 1,500 feet southwestward as the main lower level of the mine proper. About 250 feet above this, the third, or Jones, an old tunnel now inaccessible, extends from a point near the mouth of the Hanauer 2,000 feet west-southwest. From the northwest this ground is entered by two tunnels—the Ætna (elevation 1,976 feet), which extends from the north side of Crescent Ridge in Thaynes Canyon over 2,000 feet in a southerly direction to the head of the main Crescent incline connecting with the Hanauer and Alliance level, and the Antelope tunnel (elevation 1,915 feet), starting in Thaynes Canyon about 1,500 feet west of the Ætna tunnel and extending southward parallel to it for about 1,900 feet, connecting with the west end of the main mine workings. The main zone of workings lies above the Hanauer tunnel level (No. 4 level, elevation 1,645

feet) and comprises four main levels, with some old work at about ten higher levels and connections at the east by the main Crescent incline, at the west with certain levels by the Antelope incline, and at various intermediate points by working inclines. About 500 feet north of the main zone, between the Ætna and Antelope tunnels, about 300 feet east of the latter, are the old Apex workings, comprising a tunnel about 400 feet long and a narrow zone of workings at four levels about 300 feet in length. The Boss shaft (elevation of collar 2,175 feet), connecting with the old Boss workings, lies about 300 feet east of the junction of the Ætna tunnel and Crescent incline. In brief, the main zone has been developed for a distance of about 3,000 feet horizontally and 1,500 feet vertically. This group of workings is connected by the Alliance tunnel and crosscut and the Alliance-Silver King raise with the main Silver King mine.

ECONOMIC GEOLOGY.

Character of country rock.—The general geology of this region has been described under the main Silver King property. It is characterized, as in Crescent Ridge, by Triassic limestones of the Thaynes formation and on the valley bottom and the lower slopes by glacial drift. Immediately underlying this thick drift is the same limestone, in turn underlain along the base of Crescent Ridge and to the east in the vicinity of the Hanauer tunnel, by the Woodside shale. Exploration beneath the drift east and northeast of the mouth of the Hanauer tunnel would probably reveal the Park City formation under the Woodside shale, from about the line of Walker & Webster Gulch to Empire Canyon. The drift is deep, the Hanauer tunnel lying in it for the outer 200 feet before entering bedrock. The Crescent Ridge ground is composed of the sediments of the Thaynes formation, with red shale overlying on the Thaynes Canyon slope.

As a whole Pioneer Ridge at the head and Crescent Ridge beyond at the north are made up of Triassic sediments in which a small dike of basic porphyry outcrops. The wall inclosing the Jupiter Hill amphitheater on the west is composed of highly metamorphic sediments of the Thaynes and Ankareh formations, capped just above the Apex mine by the quartzitic Nugget sandstone. Adjoining on the north are the characteristic beds of the Thaynes formation inclosing the Sampson or Crescent amphitheater.

Underground the Alliance tunnel enters first Weber quartzite and then passes into the Park City formation. The red shales cut in the eastern part of the Hanauer tunnel apparently overlie the Park City formation penetrated below by the Alliance tunnel and belong stratigraphically under the limestones of Crescent Ridge that have been cut in the Crescent workings. The country rock exposed on the Hanauer tunnel level comprises brown and gray calcareous sandstones, gray and green limestones, argillite, and quartzitic sandstone—all metamorphic members of the Thaynes formation—and coarse altered diorite porphyry and biotitic basic porphyry. Along the Crescent inclined shaft 60 feet above siliceous sediments are exposed, also on the next higher level. On the tunnel leading from the Crescent incline westward to the surface and on the Antelope tunnel to the west from the head of the west incline similar metamorphic sediments, red shale, and dioritic and basic porphyry are cut. Some marmarization of limestone was noted.

Structure and deformation of country rock.—These sediments dip generally 30°–40° NW. and are only locally disturbed by dragging along faults. The dominant deformation is faulting on a zone of well-defined persistent fissures. These trend northeast and southwest and dip southeast. The main member of this series is the Crescent fault, on which the Thaynes formation is apparently offset from Empire Canyon westward to Walker & Webster Gulch, a distance of nearly 5,000 feet, on the north side. A parallel zone on the south is marked by the saddle just north of Jupiter Hill and zones of fractures crossing the head of Thaynes Canyon southwestward. North of the Crescent fault—that is, on the downthrow side—are outcrops of the strong complex series of northeast-southwest fissures that determine the productive ground of this property.

On the surface the fissures are clearly shown. For about 1,500 feet north of the master fault of this system (the Crescent), the ridge is divided into a number of slices or narrow blocks by several parallel fissures striking N. 80° E. In addition to these major faults there are numerous minor parallel faults and a few oblique ones traversing the four main fault blocks. They are doubtless sympathetic with the main Crescent fissure and the seat of displacement of

similar phase—that is, they generally dip to the north. Underground the prevailing trend of the fissures composing this zone is N. 50°–70° E., and the dip is usually toward the southwest at a steep angle. The direction of displacement so far as could be judged from local features was down on the south, and the direction of movement, although not clearly indicated, was apparently directly up and down the dip.

Occurrence of ore bodies.—Ore occurs in two distinct modes in this property—as normal lodes and as normal replacement beds. These bodies lie chiefly in or near the fracture zone, called the Crescent "vein," and some in minor members of the same fracture zone farther north, in the footwall. The Crescent "vein" has been worked in the Crescent, Apex, Sampson, and Hanauer mines including the Boss and Jones workings. It varies in form between a single clean fissure, a zone of fractures, and a zone of breccia cutting northwestward, dipping beds, and intrusive rocks, and it carries characteristic banded ore and brecciated ore. The walls are made up of metamorphic sediments and both varieties of porphyry, but the hanging wall is largely porphyry.

Of far greater known extent than the lodes are the bedded replacement bodies. These were worked to a small extent in the early days in the Crescent mine above the present Hanauer tunnel level, the discovery of ore in beds being the cause of contention between the owners of the Apex Climax mines, but the principal beds of ore known in this ground have been opened since the consolidation that formed the Kearns-Keith property. These beds were found in the footwall of the main lode at the west end of the Hanauer tunnel dipping gently northwest. At this point pyritized sheeted porphyry forms the hanging wall of the lode and a succession of metamorphic calcareous beds comprising pure limestones, siliceous and sandy beds, and metamorphic limestones with marble make up the footwall. Three distinct ore horizons or beds favorable to the deposition of the ore were recognized. The principal occurrence at the time of visit extended from the lode in a lens stretching 100 feet along the fissure and 65 feet down the dip and pitching slightly toward the southwest. This lens was made up of two beds, the upper having a maximum thickness of 20 feet and an average of about 7 feet and the lower ranging from 4 to 10 feet in thickness with an average of about 5 feet. The upper ore bed lay immediately under a clear, tolerably pure massive limestone, partly marmarized, and over a siliceous limestone, which forms also the hanging wall of the lower ore bed, and this in turn has a footwall of siliceous limestone. The sedimentary bed that the large upper ore bed replaced appears from the portions around the periphery of the ore body to have been a nearly pure limestone now locally marmarized.

The two beds described above are characteristic. In brief, it appears that ore occurs in a main northeast-southwest fracture zone and in some minor sympathetic fractures in the form of bands and breccia and extends into the footwall along certain limestone beds that are in places connected along transverse feeding seams and flat oblique slips.

Character of ore.—The ore is lead with which zinc and iron are associated, carrying silver and some gold. The silver and lead are reported to run higher in the ore from the beds than in that from the lodes. Oxidation has descended below the upper levels to the higher of the ore beds, which was being worked at the time of visit at the level of the Hanauer tunnel. The lower bed, except for a slight rusting, was entirely sulphide. It appears also that oxidation increases toward the southwest and that zinc increases greatly in the same direction.

The minerals constituting these ores are galena, zinc blende, chalcopyrite, pyrite, and silica. Galena occurs in both bedded and fissure ore, perhaps being more massive in the beds. The most abundant mineral in the bedded ores examined was zinc blende. The gangue is fine granular silica. Although all these minerals are found in both types of ores, chalcopyrite was more common in the bedded and pyrite in the fissure ores in the specimens studied. Here and there blende and pyrite were crystallized, but in the bedded ores the component minerals are usually in grains up to the size of a pea and present a contemporaneous intergrowth.

BALMOUNT GROUP.

The Balmount group embraces a number of claims, which extend westward from the head of Walker & Webster Gulch across the head of Pioneer Ridge into Thaynes Canyon. At the time of visit, in 1903, the main development was an abandoned tunnel and a shallow shaft.

In general this ground is made up of highly metamorphic argillite, sandstone, and quartzite cut by a narrow dike. These sediments dip generally northwest and are traversed by many distinct east-west fractures. The amphitheater at the head of Walker & Webster Gulch is floored with glacial débris and talus from the overlooking ledges of Jupiter Hill, much of this material being distributed in perfectly preserved kames. At the time of visit a shaft was being sunk in this locality, which, it was stated, had passed through this waste material for 70 feet and penetrated underlying metamorphic sediments for 30 feet.

The tunnel in the Thaynes Canyon slope lies about 1,000 feet north-northeast of Jupiter Hill, at an elevation of 9,500 feet. It runs southeastward and was accessible for about 1,200 feet. It lies in metamorphic limestone, argillite, and quartzite and opens several east-west fissures. About 700 feet from the mouth a vertical northeast fissure showed good staining and some mineralization. No ore, however, was observed.

FAIRVIEW INCLINE.

The Fairview incline and connected workings are situated on the north slope of Walker & Webster Gulch, about 600 feet northwest of the mouth of the Alliance tunnel. They date from an early period in the history of the camp and were opened along a fault contact between the Park City formation and the underlying Weber quartzite. The workings observed comprise a main incline which appeared to descend nearly vertical, a minor incline, lateral workings along the zone, and surface prospect holes. It is understood that some ore was found, and at the time of visit signs of mineralization were noted. The workings were inaccessible. The locality is said to have attained some prominence in connection with a suit involving the ownership of ore bodies that were developed through the main Silver King mine. At the date of visit the property was owned by the Silver King Consolidated Co.

WOODSIDE GULCH.

GEOLOGIC FEATURES.

Woodside Gulch is the westernmost of the narrow valleys of three small streams which unite at Park City to form Snake Creek. It heads on Crescent Ridge between Walker & Webster Gulch and Thaynes Canyon and descends rapidly toward the northeast to the southern part of the town. Perched on the north side of Empire Canyon and Walker & Webster Gulch and sloping steeply (1 foot in 6) down to the master valleys, its shallowness, high level, and steep grade suggest its comparatively recent origin. Its position was doubtless assumed during the occupation of the area on the south by an ice lobe, and so the course may be regarded as superimposed. Geologically it cuts across the dip of the three basal formations in the western limb of the Park City anticline—the Woodside shale, the Park City formation, and the Weber quartzite. The moderate dip of the beds toward the northwest is interrupted in the middle course of the gulch by fracturing and faulting, commonly along northeast-southwest planes. No intrusive rocks were found outcropping in this locality, though considerable coarse diorite porphyry on the dump of a tunnel near the Silver King shaft suggests that it occurs there near the surface. Glacial débris blankets the surface south of the Silver King shaft and around the headward part of this gulch. The ore bodies thus far discovered in this vicinity occur either as lodes in fracture zones or adjacent to fissures along limestone beds as replacement bodies. The details of the geologic occurrence of these ores are given below in the descriptions of the several properties, the Silver King, Woodside, and Alice.

SILVER KING MINE.[1]

SITUATION AND HISTORY.

The Silver King mine is situated in Woodside Gulch, 1 mile southwest of Park City.

The Silver King claims, Nos. 1, 2, and 3, were located about 1889 by Martin McGrath and W. H. Dodge. During the preceding year shipments of ore of high grade were made by lessees from the Tenderfoot claim of the Woodside group, which attracted the attention of

[1] In the detailed descriptions the mines are treated according to their status at the time of examination. Thus those properties then a part of the Silver King mine, as the Mayflower, Fairview, etc., are embraced in the description of that mine, but those that have been consolidated with it since then, including the Kearns-Keith and Woodside, are treated independently.

prospectors to this region. A large cropping of a great shoot of rich lead-silver ore was accidentally discovered on the Mayflower claim, farther west, from which lessees who began shipments in 1889 took out $500 worth of ore a month for five months. Their lease was bought by five men, who in quietly working out this shoot found that it continued westward into Silver King ground. They thereupon obtained a lease and bond on the three Silver King claims. In the summer of 1892 these five, David Keith, W. V. Rice, Thomas Kearns, A. B. Emery, and John Judge, took up the bond and paid the owners, W. H. Dodge, Martin McGrath, John Farrish, and Cornelius McLaughlin, $65,000 for the property. The Silver King Mining Co. was then incorporated for $3,000,000, divided into 150,000 shares of a par value of $20. Organized and managed by men who were experienced in mine operating and in business affairs, the property quickly attained high rank among bonanza silver-lead mines.

The Silver King shaft was sunk 700 feet with a single compartment before drifting, thence was sunk with three compartments, and subsequently two additional compartments were raised from the 700-foot level to the surface, thus affording a three-compartment shaft from collar to sump. Since that period, when 100 men were employed, the property has been rapidly developed without serious setback. Although litigation has arisen concerning various apex claims, satisfactory settlements have been reached in the Mayflower and Fairview cases by favorable decisions; in the St. Louis case by purchase. The Silver King consolidated case at present writing is in the courts. The property has been increased by adding to the original three claims several groups, including the Mayflower, Alliance, Massachusetts, Fairview, Park City, Kearns-Keith, and Woodside, until in 1904 it embraced 80 claims. Early in 1907 the McGregor group was taken up and all the holdings were consolidated under the name of Silver King Coalition Mines Co.

Since paying the first dividend of 25 cents a share, amounting to $37,500, in 1893, the yearly amount has steadily increased until in 1901 it reached $1,300,000, which was maintained for four years. The dividends year by year are given in the following table prepared from figures supplied by the company:

Dividends paid by the Silver King Mining Co. from 1893 to 1908.

1893	$37,000	1901	$1,300,000
1894	150,000	1902	1,300,000
1895	300,000	1903	1,300,000
1896	412,000	1904	1,300,000
1897	487,000	1905	1,200,000
1898	462,500	1906	750,000
1899	475,000	1907	367,410
1900	1,000,000	1908	744,300

The total amount of dividends paid up to January, 1910, is $12,334,885.

The property was for several years the largest dividend payer in the State and among the largest in the country. With greatly increased holdings, including a large tract of unexplored ground within the general ore-bearing zone, exploration and development are being conducted vigorously, in order to maintain reserves and thus keep up the high standing of the property.

PRODUCTION.

The property began to produce in 1893, when, though most silver mines were closed, owing to the depression in metal prices, its total shipments amounted to 5,219,290 pounds. From that time its output was rapidly increased until 1903, but since then it has been somewhat curtailed. The total production to 1908 inclusive is 458,940 tons, the details of which are given in the following table, compiled from data kindly supplied from the private records of the company. The production for 1908 and most of 1907 is that of the new consolidation known as the Silver King Coalition Mines Co.

Production of the Silver King mines from 1893 to 1908.

Year.	Tons.	Lead, pounds.	Silver, ounces.	Gold, ounces.	Copper, pounds.	Net value.
1892 *a*	2,885					$94,347.85
1893–94	13,830					245,004.70
1895	16,309	14,599,820	756,660	1,950		677,852.37
1896	20,563	17,641,159	945,184	2,439		762,363.88
1897	23,453	22,508,848	1,190,408	3,706		1,077,691.18
1898	24,587	23,122,672	1,227,812	5,222		1,160,354.89
1899	28,477	25,271,883	1,288,953	6,749		1,404,939.72
1900	31,368	26,691,358	1,654,990	6,807		1,610,484.97
1901	34,083	28,641,812	2,105,738	8,751		1,854,886.24
1902	40,170	33,057,194	2,593,760	10,061	248,300	1,881,925.78
1903	46,712	35,033,300	2,411,418	11,504	136,277	1,863,481.07
1904	42,559	32,026,009	2,219,533	10,396		1,824,204.41
1905	39,810	25,082,280	1,788,595	12,542		1,582,411.22
1906	29,820	15,542,439	1,359,367	7,293		1,247,123.48
1907	32,372	20,598,007	1,337,498	4,128		1,254,274.51
1908	31,942	27,760,909	1,606,934	3,058		1,345,202.37
	458,940	347,577,690	22,486,850	94,606	384,577	19,886,548.64

a Estimated in part.

PLANT.

The policy of the management from the outset has been to have the best. This policy has been followed not only in the mechanical equipment of the mine, but also in all surface improvements, including provision for employees. The Silver King shaft is equipped with a steel gallows frame, a Corliss engine of high power and efficiency, a complete compressor plant, a machine shop, and a change house. Other surface improvements include an attractive boarding and bunk house, in which is the mine office, a sampler, a concentrating mill, and an aerial tramway. (See Pl. XLI, *A*, p. 148.) The sampler is equipped with upper and lower bins of 600 tons capacity each, four sets of Vezin samplers, and Cornish rolls with bucket conveyors, and all necessary devices to render the sampling as nearly correct and automatic as possible.

Both crude ore and concentrates go to the sampler. The crude ore goes direct from mine to crusher, the concentrates are elevated from the foot of the mill to the head of the sampler, and the slimes, after being reduced to 10 or 12 per cent of moisture, are elevated from the drier to the head floor, where they are sampled by hand. In the regular sampling after the ore is crushed a 20 per cent cut is made automatically by a Vezin sampler, the 80 per cent balance going back to the bins and the cut passing to finer Cornish rolls, then to the next Vezin sampler for a similar cut, and so on four times; on special lots six sets of cuts are taken. Five men only are required to operate the entire sampler—one fireman to coal the engine, one man at the bins, one at the feeder, one extracting waste, and one on the sampling machine.

The concentration mill, erected in 1898, is equipped in two duplicate units, to treat about 200 tons a day. It differs from the other mills of this and adjacent camps in being equipped with a filter press for the treatment of slimes. The results attained in milling the Silver King ores are very satisfactory to the managers. The equipment and operation of the mill are fully described under "Reduction" (pp. 31–32), and the aerial tramway for transporting ore from the sampler to the railway station below Park City and bringing fuel and supplies thence to the mine is described on page 24, under "Transportation."

DEVELOPMENT.

The Silver King ground has been opened through a shaft 1,325 feet deep and an extensive system of drifts, stopes, and connections. The main workings lie in a zone that extends from the shaft roughly east and west a maximum distance of about 6,000 feet and has an average width of about 700 feet. Levels have been turned from the shaft at depths of 300 (365), 700 (722), 800 (821), 900 (923), 1,100 (1,091), and 1,300 (1,292) feet, and others run from underground connections at 750, 850 (860), 1,000 (982), 1,150, 1,200 (1,170), and 1,250 (1,209) feet.

In general these workings extend from the surface downward in a southwesterly direction, so that the upper levels lie at the northeast end of the mine and the deeper ones at the southwest. There are two exceptions, namely, a long crosscut on the 1,100-foot level, which extends from

the shaft southeastward (about 1,800 feet at the time of visit), and the 1,300-foot level running the entire east and west length of the mine (about 6,600 feet).

At the east end the Silver King mine is connected by the 700-foot level with the Mayflower and thence with the Woodside workings, and the western part is connected by intermediate levels and the Alliance incline and by the Alliance raise and crosscut with the Alliance tunnel, and thence with the Kearns-Keith mine in Walker & Webster Gulch. By the raise from the Alliance to the Hanauer tunnel level and thence up to the upper levels through the old Crescent and Apex workings under Crescent Ridge, connection is made with the head of Thaynes Canyon. Thus the northern great group of mines, like the southern group, are connected underground.

ECONOMIC GEOLOGY.

Character of country rock.—The Silver King property lies on the western flank of the Park City arch. It embraces considerable areas of Woodside shale on the west and of Park City formation and Weber quartzite, which successively underlie the Woodside toward the east, and an extensive blanket of glacial material. The Woodside shale extends south from Nigger Hollow along the northwest slope of Woodside Gulch and disappears farther south beneath glacial moraines. Its exposure on the slope above and northwest of the Silver King boarding and bunk house is the best observed in the entire district. At this locality it appears as a remarkably uniform mass of thin, evenly bedded dark-red or maroon shale with a few intercalated beds of buff fine-grained sandstone. The thickness here can not be accurately determined owing to the existence of known but indeterminable deformation. The Silver King Consolidated shaft descended through 800 feet of this shale, which dipped on an average about 30°, thus indicating a thickness of about 700 feet, although considerably more would be expected, to judge from the exposure above the bunk house, and this formation in Big Cottonwood Canyon showed a thickness of about 1,180 feet. The Park City formation is also better exposed in this vicinity than elsewhere within the limits of the district. Its exposure extends from the Woodside and Mayflower ground in Treasure Hill south across Woodside Gulch and caps the east end of the spur between Woodside and Walker & Webster gulches, then disappears on the southwest beneath glacial deposits. Its total thickness, as indicated by the exposures in Treasure Hill, is about 700 feet, but this estimate may be in error through probable faulting. The thickness of this formation in the undisturbed area of the Big Cottonwood type section was 590 feet. The general lithologic character of this formation on the spur between Woodside and Walker & Webster gulches is a sandy upper part underlain by a drab shale and calcareous sandstone, giving way to a succession of limestones. The important basal portion, better shown on the slopes of Treasure Hill near the Woodside and Mayflower mines, reveals a gradual and indistinct transition from the Weber quartzite through sandy beds into a calcareous series about 75 feet thick, with certain significant intercalated sandstone beds and giving way to a series of varicolored shales. The Weber quartzite underlying the Park City formation extends along its southeast contact from the Woodside shaft to the Alliance tunnel and occupies the southeastern part of this company's ground. It forms the prominent ledges on the north side of Empire Canyon from the Alliance tunnel northeastward and those on the north side of Woodside Gulch from the Woodside shaft northeastward. In this area the demarcation between the quartzite and the overlying Park City formation is not sharp but rather a gradual transition. Hence the precise location of the geologic boundary between these two formations was exceedingly difficult to determine. Wherever there was doubt, it was aimed to regard the top of the main quartzitic series as the line of contact. The quartzite itself presents here its normal characteristics—massive bedding, fine, even grain, and light brownish gray color.

Unfortunately, a large portion of this important area, which is significant stratigraphically and extremely complex structurally, is deeply covered with glacial drift. This mantle hides several geologic features that are of supreme value in the interpretation of the geologic structure and hence in planning the cheapest and best development of the ground beneath. This drift area, which is the largest within the main area of productive ground, heads in the amphitheaters overlooked by Jupiter Hill and Crescent Ridge and extends northeastward to Empire Gulch,

being deeply incised by Walker & Webster Gulch and forming the head of the divide between that and Woodside Gulch and the prominent lobe west and southwest of the Massachusetts shaft. It is made up of loose, ill-sorted angular blocks of the metamorphosed members of the formations, mainly the Woodside and Thaynes, about the source of the local ice flow. The deep cut made by Walker & Webster Gulch between the Hanauer and Alliance tunnels, that by Empire Canyon south of the Massachusetts shaft, and numerous prospect shafts, some of considerable depth, tend to show that this deposit of glacial drift is thick. It necessitates much extra work in mining operations beneath these deposits where nothing is revealed on the surface.

Underground the same sedimentary formations are found, though the bulk of the workings lie in the Park City formation. The Silver King shaft descends about 800 feet in the Park City formation and the rest of its depth, about 500 feet, in the Weber quartzite. In general the deeper and the more southern workings are in quartzite and the upper and more northern in limestone. Thus the 1,300-foot level, with a possible small exception, the 1,250 and 1,200 foot levels, and the southern parts of the 1,100, 1,000, 900, and 700 foot levels are in Weber quartzite, but the 300, 750, and 800 foot levels and the northern parts of the 700, 900, 1,000, and 1,100 foot levels are in the Park City formation. Throughout these extensive workings intrusives are notably scarce. On the 300-foot level a small mass of peridotite is exposed 200 feet northeast of the King shaft; on the 750-foot level the basic porphyry again appears, here as a small sill; and on the 800-foot level about 100 feet northeast of the shaft blocks of diorite porphyry occur in a northwest fracture zone. On the 1,100-foot crosscut running southeast coarse diorite porphyry is exposed at its junction with the southwest drift on the vein, again in a small sill about 100 feet farther southeast, and at the face. On the 1,200-foot level, at the southwest end of the mine 1,800 feet southwest of the Donkey winze, a dike of coarse sericitized pyritized diorite porphyry has been followed along its strike (S. 70° W.) for 105 feet.

Structure and deformation.—The sedimentary beds in this locality strike generally northeast and southwest and dip 22°–30° or rarely as high as 40° NW. These beds are deformed by many fractures, on some of which extensive and profound faulting has occurred. The structural influence of the intrusive rocks, which are few and comparatively small, is negligible. The influence of the faults, however, in shifting the ore-bearing formations many hundred feet, and in forming places for ore deposits or truncating others, is most important and their correct determination thus becomes of the highest necessity in proper development of the ore bodies. The faults are very difficult to decipher and to correlate owing to the fact that they are largely hidden beneath glacial drift.

The master faulting in this region appears to have taken place in a northeast-southwest direction, on a zone known after its leading member as the Crescent fracture zone and, next in importance and perhaps incidental to the former, along the Massachusetts fracture zone. The Crescent fault is indicated on the surface at several points. Thus at the junction of Crescent Ridge with Pioneer Ridge it brings the conglomeratic quartzite and the immediately overlying Ankareh shale down on its south side against fine-grained shaly rusty calcareous sandstone and gray limestone of the Thaynes, the next lower formation. Farther east, in the supposed course of this fracture, lie heavy deposits of glacial débris. Thus at the junction of the broad flat-topped spur between the adits of the Hanauer and Alliance tunnels with the higher ledgy portion on the south the prominent scarp-forming beds of the Thaynes formation end abruptly on the north against glacial material and sediments, apparently of the Park City formation, along well-defined faults directly in the northeastward course of the Crescent fault zone. Still farther east, beyond Empire Canyon and about 500 feet south-southeast of the mouth of the Daly-Judge drain tunnel, in the course and trend of this great fracture zone, is further sheeting and fracturing. Underground, about 525 feet from the mouth of the Daly-Judge drain tunnel, limestone of the Park City formation is exposed faulted down against the Weber quartzite on the north along a clean-cut fault zone. This fault agrees in position, trend, dip, and geologic character with the main Crescent fault but is probably combined to some extent with the Massachusetts fault. So far as known at the time of examination, it had not been developed in the extensive mine workings of Walker & Webster Gulch but probably lies west of the main Silver King workings and east of the Kearns-Keith mine.

Most of the rocks that outcrop along the west wall of Empire Canyon (Thaynes formation) end abruptly on the north against a northeast-southwest fracture zone and reappear in Crescent Ridge on the other (north) side of the zone. These observations indicate a displacement along a northeast (55°–70°) fracture zone, resulting in a surface offset of about 3,000 feet southwestward on the north side of the zone. The economic effect of this displacement is that the Park City and Thaynes formations, instead of continuing normally from the Daly West down Empire Canyon, are offset to the west and continue northeastward along Walker & Webster and Woodside gulches.

The second great fault zone, the Massachusetts, lies north of the Crescent and diverges from this junction near the Massachusetts shaft and Daly-Judge tunnel, trending northwest across Walker & Webster Gulch. At the collar of the old Massachusetts shaft is a clearly defined fault striking N. 70° W. and standing vertical between Weber quartzite on the north and banded limestone and calcareous sandstone members of the Park City formation on the south. Further, members of the Park City formation appear as ledges projecting through the drift along the west wall of Empire Canyon, in prospect holes southward along the road nearly to the dump at the Daly No. 2 shaft, along the bottom and west side of the gully descending northeastward from Daly No. 2 shaft, and on the south side of Walker & Webster Gulch west of the Alliance tunnel. (See Pl. XXXIX, p. 132.)

Beyond these scattered outcrops little could be found owing to the thick blanket of glacial drift. The evidence tends to show, however, that in the hanging wall of the Ontario fracture zone and overlying the Weber quartzite, the Park City formation between the Daly No. 2 shaft and the Daly-Judge drain tunnel descends westward beneath the drift and the Woodside shale. It further appears that this formation is traversed and displaced beneath the drift by the Crescent fracture system and is truncated on the north by the Massachusetts fault, for immediately north of this fault prominent ledges of Weber quartzite outcrop in the vicinity of the Daly-Judge tunnel and Massachusetts shaft, also bordering the road up to Alliance tunnel, and in the north side of Walker & Webster Gulch to a point about 150 feet above the United States land monument No. 5. At that point the quartzite gives place upward to the Park City formation, thus indicating a horizontal offset on the Massachusetts fault zone of about 2,500 feet toward the west on the north side. The extension of this zone northwestward across Woodside Gulch in a direct course is not evident. It may either be represented by the relatively small fault followed by the gap which lies southwest of the direct course, although this is in no sense commensurate with the main fault, or it may have been truncated by a later east-west fault of the series that descends Crescent Ridge toward the Silver King shaft.

Underground the fault is cut in the Daly-Judge tunnel and has been extensively explored in the Alliance tunnel, but in the Silver King mine proper it could not be positively identified at the time of examination. It is not unlikely that this fault is represented by the vein cut by the southeast crosscut on the 1,100-foot level and marked by faults crossing the connection between the Silver King and the Alliance. In the Alliance tunnel it was cut about 825 feet in from the mouth. At this point its trend is N. 70°–75° W. and it dips 68°–70° S., but the testimony of the slickensides is contradictory. This fracture has been followed west for about 800 feet, and at a point about 2,500 feet beyond the Alliance-Silver King connection it cuts strong faults of accordant strike and dip.

In brief it has been found that the sedimentary beds in Empire Canyon have been offset to the west in Walker & Webster and Woodside gulches along an east-west fault wedge inclosed between the Crescent fault (5,500 feet) on the south and the Massachusetts fault (2,500 feet) on the north. These two fault zones, the Crescent (belonging in the Ontario fault series) and the Massachusetts, comprise the most important structural features in this region.

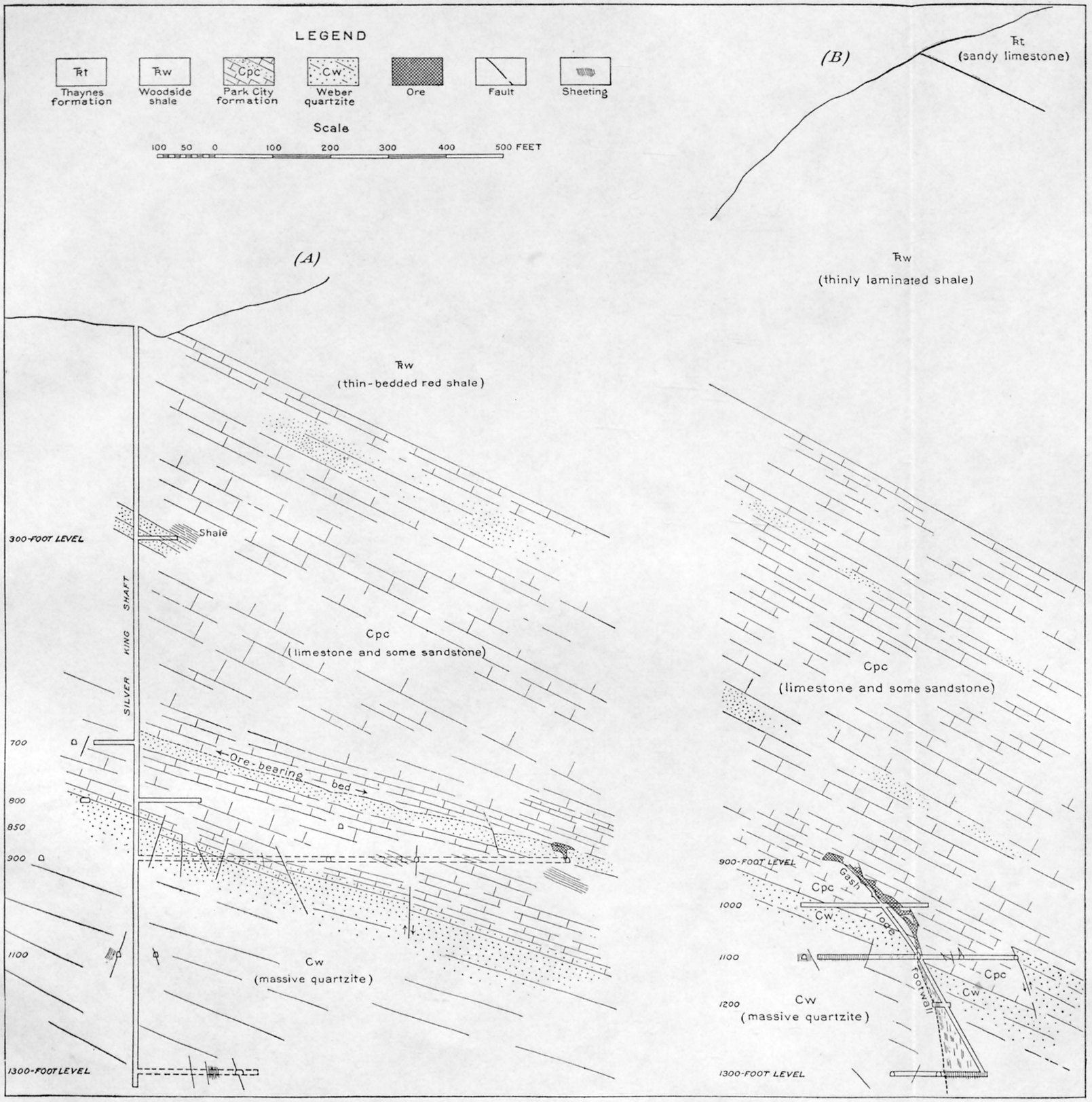
The structural features above described appear also underground in the Silver King mine. The prevailing dip of the bedding is 20°–35° NW. The chief modification of this monoclinal structure is that produced by fracturing and faulting. Broadly viewed this mine may be said to lie along a northeast-southwest fracture zone in Carboniferous limestone.

In the central portion of the mine, that directly tributary to the Silver King shaft, four major fissures or zones of fissuring have been revealed—the north, "gash," "gold ledge," and Massachusetts zones. Continuations, or branches, of these and others in the same general zone have been followed toward the southwest, and other minor ones have been cut toward the southeast (for example, one on the 700-foot level south of the shaft, whose discovery was reported in 1906) and toward the east (for example, those traversed by the 1,300-foot level out beneath the Mayflower workings). The four main zones as a whole are made up of fairly persistent fissures, with sharp walls slickensided in many places, having a fairly constant dip of 50°–80° NW., and a somewhat wavy strike of N. 50°–80° E. Other fractures are marked by zones of brecciated and crushed material without definite walls. Apparently the most common displacement on them is a relative movement of the northern or hanging-wall side ranging in direction from directly down the dip to an angle of 45° with it and in amount from a few feet up to more than a hundred feet. A few north-south and northwest-southeast faults are known, which appear to be later than the others, but they are not important.

The north zone is best seen on the 900-foot level, where it is made up of three distinct major faults with several sympathetic ones. The first, 300 feet northwest from the shaft, strikes N. 60° E. and dips 78° NW.; the second, 150 feet beyond, strikes a trifle nearer east and stands vertical; and the main fault, about 300 feet beyond, strikes N. 50° W. and dips 85° NW. The movement on the first of these, which has a quartzite footwall and a gray limestone hanging wall, was relatively down on the north side at an angle of 70° SW., and on the main fault, likewise, the hanging wall appears to have been dropped. The beds traversed by this zone at this depth are the basal or transition and lower limestone members of the Park City formation, which play a significant part in ore deposition, as will be described under "Occurrence of ore bodies" (pp. 186–187).

The apparent continuation of the main fault has been followed on the 1,000-foot "hanging-wall" drift for 500 feet in a S. 75°–80° W. direction, dipping about 60° NW. between limestone walls, and on the 1,100-foot level 200 feet southwest, cutting the basal series of calcareous arenaceous beds at an angle of 67°.

Lying immediately south of these deeper workings on the north member is a very strong fracture zone known locally as the "gash." This zone has been opened at a point about 1,700 feet west-southwest of the Silver King shaft from the 900-foot to the 1,300-foot level and along the strike for 400 feet on the 1,000-foot level and 800 feet on the 1,100-foot, diminishing to 5 feet on the 1,300-foot. In general it strikes N. 50°–60° E. and dips 48°–87° NW., the dip being about 50° in the upper and 70° in the lower portion. (See Silver King structure sections, Pl. XLIII.) It is a zone of dislocation made up of distinct fissures with slickensided walls, zones of fractured material, and broad zones of sheeting, one on the 1,300-foot level attaining a width of fully 75 feet. The direction of movement, judged by slickensides, varied, being directly down the dip on the 900-foot level in the line of the Donkey winze and flatter at some other points. The character and amount of dislocation are shown in a general way by the formations inclosing this zone. Near the Donkey winze the Park City formation apparently extends in the footwall down to a point about midway between the 1,000 and 1,100 foot levels, and in the hanging wall from 50 to 75 feet lower. On a member of this same zone, however, the displacement about 200 feet east of the Donkey winze at the "big chute" between the 900 and 1,000 foot levels appeared to have been at least 40 feet on the hanging-wall side. On the 1,200 and 1,300 foot levels the zone lies entirely within Weber quartzite. At this, the greatest depth exposed, it seems to be distributed in the form of a broad zone of sheeting rather than restricted to a definite, more strongly marked zone as above. Laterally the fractures included in the "gash" zone, or branches of them (disregarding for the present the contents of this zone), seem to persist beyond the limits of exploration. Well-defined fractures of similar characteristics, which extend in the general course of the "gash" zone for 1,500 feet to the southwest, may be a continuation of either the north or the "gash" zone or of the two united.



A. SECTION THROUGH SHAFT TO NORTHEAST, SHOWING ORE-BEARING SERIES.
B. SECTION THROUGH POINT 1,100 FEET WEST OF SHAFT, ALONG LINE OF DONKEY WINZE, SHOWING OCCURRENCE OF LODE ORE IN "GASH" ZONE AND RELATION TO BEDDED ORE.

GEOLOGIC STRUCTURE SECTIONS THROUGH SILVER KING MINE.

The "gold ledge" is a strong, persistent, well-defined fracture zone which lies next south of the "gash" zone, about 100 or 150 feet on the 1,100-foot level. It has been explored on the 700-foot level for 1,000 feet, on the 800 and 900 foot levels south of the Silver King shaft, on the 1,100-foot level for more than 2,000 feet west-southwest from the shaft, and on the 1,300-foot level. It strikes on the 1,100-foot level N. 60°–80° E. and dips 50°–80° NW., the dip averaging 53° from the 700-foot to the 1,100-foot level in the vicinity of the shaft. It is in some places a single sharply defined fissure, in others a zone of crushed brecciated quartzite 5 to 10 feet wide, as on the 700-foot level east and on the 1,100-foot level about 1,100 feet west of the shaft, and in still others a wide zone of sheeting with crushing, as on the 700-foot level south of the shaft, where the zone is 75 to 100 feet wide, and on the 1,100-foot level, where it is fully 100 feet wide. The direction of movement as indicated by slickensides varies, being on the 900-foot level about 600 feet west of the shaft 60°–70° SW., on the 1,100-foot level near the "big shoot" directly down the dip, and on the 1,300-foot level about midway between that point and the shaft 63° SW. This great fracture zone lies south of and below the Park City formation and cuts the Weber quartzite throughout these workings except at one locality. At the west end of the 800-foot level about 550 feet west of the shaft and between the 800 and 900 foot levels the "gold ledge" zone cuts sandy and calcareous beds, which are either intercalated members in the Weber quartzite or the basal series of the Park City formation descended to this depth on its northwest dip, but the development was insufficient to show which. The direction and amount of displacement on this strong zone were likewise not shown, but the evidence at several points suggests that the hanging wall or north side descended. This zone appears to persist both upward in dip above the 700-foot level and downward below the 1,300-foot level with constant strength, and along its strike, although locally interrupted and perhaps offset for comparatively short distances and at other points passed by in a wall, it seemed to persist in either direction.

The Massachusetts fissure, which will be considered in the description of the Kearns-Keith mine, is believed to have been cut in the 1,100-foot crosscut toward the southeast, but at the time of visit it had been very slightly explored.

Besides these master fracture zones, several others of similar habit have been encountered. It is reported that one has been developed on the 700-foot level, southeast of the Silver King shaft since the present study was made. Several others were crosscut by the Silver King-Alliance connection, and considerable fissures have been opened at the extreme southwest end of the mine for several hundred feet.

Croppings of ore bodies.—The great shoot of rich ore that has made the Silver King mine famous has commonly been cited as evidence that the ore bodies of this district lie deep and do not outcrop. It is pointed out that the Silver King shaft was sunk to a depth of more than 700 feet before development work was started or ore struck. It is a fact, however, that the great shoot did outcrop and descended continuously to the deep levels at the west end of the mine.

The great Mayflower shoot was accidentally discovered by lessees on the Woodside mine. It is related by contemporaries that a prospector, wearied by his unsuccessful search, seated himself to rest on a large rock. His pick, which he let drop from his shoulder, struck the supposed bowlder and knocked off a chip, revealing a surface of rich ore. A little picking sufficed to prove that this "bowlder" was a mass of solid ore in place and formed the cropping of the now famous Mayflower ore shoot. The spot where this outcrop was discovered lies, it is understood, on the Northland claim, between the old Mayflower and Woodside shafts, and is marked by the entrance to an old incline.

This shoot descends westward beneath the surface and no extension of its cropping was observed. Nor were surface indications of the other great ore bodies that have been found in this ground farther west observed. It is possible that these shoots that have been opened on deep levels did not extend to the surface, and it is also possible that they did not reach the bedrock surface and there form well-defined masses of oxidized ore, which are now deeply buried and hidden by glacial waste.

Form and distribution of ore bodies.—Roughly the form of the known Silver King ore bodies may be likened to that of a long, narrow, gently sloping roof with supporting walls extending lengthwise and parallel and at one end continuing far out beyond the roof. In this analogy the roof is the locus or plane of the great bedded ore body whose apex is at the point of discovery and which dips 20°–30° NNW. to a point nearly 1,500 feet west of the main shaft at a depth between 900 and 1,000 feet. The walls supporting the roof are the northeast fracture zones in which are the lode ores. These lodes extend about 4,000 feet, mainly southwest of the Silver King shaft, their eastern portions running under and up to the bedded ore bodies.

Within the plane that includes the replacement bodies the ore lies in two main shoots and two minor branches or lobes. The principal shoot, known as the Mayflower, has been followed from the surface down and northwestward to the 900-foot level. The second shoot, situated about 400 feet south of the first, near the Silver King shaft, descends westward toward the Mayflower shoot for nearly 1,000 feet and the two unite near the "big switch." From the Mayflower shoot a lobe extends northeastward above the 900-foot level for a few hundred feet, and about 500 feet east of that, or just north of the Silver King shaft, another lobe extends due north from the Mayflower shoot for several hundred feet. The locus of the Mayflower shoot has a dip of 20°–30° NW., and within that the ore shoot pitches about 20° W. In thickness it ranges from a mere film up to 1,520 feet and in width from a narrow band to 150 feet at its branch lobe on the northeast.

The second or "fork" shoot is strong for nearly its entire course, averaging almost 75 feet in width. At the "big switch" the junction of these two shoots is marked by the largest single ore body known in the Silver King ground, which is 400 feet long, 200 feet wide, and averages about 150 feet in thickness.

The ore in the fractures, though varying from place to place in thickness and width, can hardly be regarded as localized into a definite series of shoots. The principal ore body known in these fractures is the great mass in the "gash" lode between the 900 and 1,100 foot levels adjacent to the Donkey winze. This is a lenticular body 20 feet thick in the center, which feathers out upward at the 900-foot level, ends sharply below at a depth of 1,100 feet, and thins out at the north end along a roughly vertical line. In the "gold ledge" the ore has been found in irregularly distributed benches and lenses.

Occurrence of ore bodies.—In general the Silver King ores occur in the basal part of the Park City formation in certain limestone members; also in northeast-southwest fractures between both quartzite and limestone walls (Pl. XLIII, p. 184). The geologic relations of the bedded ore to the inclosing limestone members are well shown at several points, perhaps nowhere better than in stopes opened due north of the shaft and entered by the 750-foot level and in others entered at the extreme north side of the 900-foot level. At these points are the two lobes described above as making off from the Mayflower shoot.

The shoot north of the shaft is made up of ore replacing 1 and 2 inch bands of limestone through a 2 to 3 foot member. The country rock is a soft carbonaceous limestone. It lies under a gray calcareous quartzite, locally sandy, and its footwall bed is a black cherty and blackish-gray siliceous limestone, which is in turn underlain by dark-gray siliceous beds and then dense quartzite. The replacement body on the 900-foot level lies similarly under a fine-grained gray siliceous limestone and over a fine-grained brownish-gray siliceous bed with a hackly fracture. In each of these, the clearest cases, it appears that the ore replaces parts of a calcareous member that lies over sandy or quartzitic members and under other sandy members. The exact position of this series that appears to favor ore deposition could not be determined owing to complex disturbance by faulting, but it probably lies between 40 and 100 feet above the Weber quartzite. Again at the head of the Donkey winze on and above the 900-foot level, where ore lies in bedding adjacent to the "gash" lode, the ore horizon is about 75 feet above the Weber quartzite (Pl. XLIV). Above the 800-foot level replacement ore apparently lies in calcareous members at or near the base of the Park City formation.

A. BEDS OF RICH ORE, CARRYING LEAD AND COPPER, IN WEBER QUARTZITE ADJACENT TO FISSURE.

On 1,200-foot level. Looking east.

B. FACE OF RICH GALENA ORE IN "GASH" VEIN OVER DISTINCT FOOTWALL FISSURE.

On Malloy level. Looking southwest.

ORES IN SILVER KING MINE.

In each of these occurrences the bedded ore in the limestone lies adjacent to strong northeast-southwest mineralized fractures or lodes. Thus the flat ore body stoped on the 900-foot level is contiguous to the fractures cut by that level, the flat ore bed at the head of the Donkey winze is contiguous to the great shoot in the lode known as the "gash," and the long stopes directly west of the Silver King shaft at the 700-foot level mark the position of beds that lay directly along and near the "gold ledge" northeast fracture zone. The exact relation between the lode and replacement bodies could not be observed. Lenses, bands, and blocks of ore lie within the fractures, and beds of ore abut immediately against these lode ores and, separated only by slips, make off in the walls adjacent to the fractures. The flat ore bodies usually run along calcareous beds, but here and there, as on the 1,000-foot and 1,200-foot levels, they replace beds of quartzite, extending for 25 feet back from the fissure.

The relation of porphyry and ore is not well shown in this ground. On the 1,100-foot level in the crosscut running east from the Silver King shaft a contact of porphyry with calcareous sandstone is exposed in which a little mineralization took place at the contact, but at the west end of the 1,200-foot level a contact of porphyry with quartzite that was opened for a considerable distance failed to show ore.

Character of ore.—The Silver King ore yields silver and lead with minor amounts of gold and copper. High-grade crude ore makes up the greater part of the output, the concentrates furnishing only about one-third to one-fourth of the lead, between one-third and one-fourth of the silver, barely one-fourth of the gold, and practically none of the copper. (See table, p. 188.) The greater part of the ore is sulphide.

The most abundant ore mineral is galena, with which anglesite and some cerusite are commonly associated. An advanced stage in oxidation that is particularly characteristic of the Silver King lead ores yields the waxy and ocherous yellow oxides containing antimony and arsenic, regarded by Dr. Hillebrand as antimonate and arsenates of lead (bindheimite). Gray copper (tetrahedrite), the most common copper mineral, yields azurite and malachite and in places a little chrysocolla. Chalcopyrite is rare. Pyrite of the fine-grained granular variety occurs in small amount in seams. Sphalerite in small quantity is locally present.

No ore minerals of silver or gold were recognized. The silver lies mainly in the tetrahedrite and galena. The ore that was richest in gold (from the "gold ledge" on the 700-foot level) was a rusty ocherous material, apparently an oxidized residue of pyritic ore.

As gangue a small amount of quartz is usually present, in addition to a little pyrite and in places masses of sphalerite. Fluorite was found at one point, where it was associated with oxidized replacement ore.

The characteristic Silver King ore is massive, coarse, cleavable galena with intergrown areas of tetrahedrite, but along the porphyry contact and lining vugs there are anglesite, cerusite, yellow oxides, and malachite, with a little quartz. Ore of this type is perhaps more common in the deeper parts of the lodes, although thick beds of solid, coarse, cleavable galena replace members in the footwall of some lodes. The replacement ores, which lie in the limestone mainly from the 900-foot level upward, are largely altered to sulphates, carbonates, and oxides. Some lode ores below this level are highly oxidized, and it is noteworthy that the most completely oxidized lead ore encountered in the mine was on the 1,200-foot level at the west end.

No consistent difference between the replacement and lode ores was noted beyond the abundance of anglesite in the higher-lying replacement deposits and the possibly more common occurrence of tetrahedrite in the lode ores.

Tenor of ore.—The output of this mine includes a rich silver-lead crude ore and a milling ore. Of the total production for the year 1904, 97,234,220 pounds, 69,035,780 pounds was crude ore and 28,197,440 pounds was of milling grade, or roughly in the ratio of two-thirds crude to one-third milling ore. The crude ore is afforded by immense bodies of practically solid clean metal and carries very large amounts of lead and silver, some gold, and in later years some copper. (See Pl. XXV, p. 106.) It is these bodies that have given the mine its wide reputation as a bonanza mine. The fines from the milling ore carried so high values, notably in silver and gold, as to lead to the adoption of the filter press for saving them. The average

value of the ore is shown in the following table, which has been compiled from the records of the company:

Average content of ore from the Silver King mine from 1895 to 1903.

Year.	Lead.	Silver.	Gold.	Copper.
	Per cent.	*Ounces per ton.*	*Ounces per ton.*	*Per cent.*
1895	47.73	46.46	0.121	.....
1896	42.56	46.67	.115	.....
1897	47.60	49.10	.164	.....
1898	48.00	49.32	.228	.....
1899	45.72	46.70	.261	.....
1900 [a]	43.73	53.96	.222	.....
1901 [a]	44.79	66.47	.274	.....
1902 [a]	43.26	68.00	.262	5.35
1903	40.12	54.24	.251	4±

[a] Crude.

WOODSIDE MINE.

SITUATION AND HISTORY.

The Woodside mine is situated in Woodside Gulch on the south slopes of Treasure Hill, about half a mile south-southwest of Park City. This ground was located in 1873 by John A. Nelson and was bought in 1874 by E. P. Ferry. Some prospecting was done and some mining on a small scale. During the first 10 years $30,000 worth of ore was produced. In 1882 some promising float, including bowlders of carbonate ore, are said to have been found, and the mine was leased to John Parry. During the succeeding five years desultory work was kept up, small shipments being made from time to time. In the late eighties and early nineties, however, attention was turned toward Woodside Gulch, and work in the mines there and on Treasure Hill adjoining became very active. The Woodside mine, which is stated to have produced ore to about the value of $700,000 up to that time, was then yielding to lessees 100 tons of rich ore a day. In June, 1889, the Woodside was incorporated with a capital stock of $1,000,000. The next year active operations were continued, the shaft being sunk to a depth of 500 feet and considerable drifting being done. At a point northeast of and lower than the old workings a new shoot was struck. Shipments gradually decreased, however, until in August, 1892, when all silver mines were feeling the effect of adverse silver discussion, this mine was closed. In the ensuing 10 years it was comparatively inactive, though some gold ore was struck by lessees in 1894 and the main shaft was sunk in 1895. In 1903, when several old properties were reopened and a number of new ones were located, a campaign of prospecting in Woodside ground was undertaken, both from the surface and from underground workings. After several months' work had failed to reveal new ore in commercial quantities the mine was again closed. Finally, in 1906, the property was added by purchase to the adjoining Silver King property.

DEVELOPMENT.

The Woodside ground has been opened through a tunnel driven from a point near the bottom of the gulch by a series of inclines connecting about a dozen sublevels and by a shaft connecting with levels at depths of nearly 500 and 600 feet. The tunnel enters the base of the north side of the gulch about 150 (138) feet below the collar of the shaft and extends north-northwest about 1,000 feet; it also connects with the shaft and extends thence westward about 1,200 feet to the old Tenderfoot-Mayflower-Northland workings. These comprise the main Tenderfoot incline, extending from the surface down through the Mayflower into the Silver King workings, several minor inclines, and about a dozen sublevels, all except one being above the Woodside tunnel level. They lie at the west end of the Woodside ground adjoining the Mayflower-Silver King ground. The 500 and 600 foot levels were driven from the shaft apparently as prospect crosscuts. The former extends from beneath the creek in a north-northwest direction about 1,700 feet, and the latter from the shaft in a south-southeast direction about 1,000 feet, having two branching drifts 800 and 1,000 feet in length running northeast and

southwest. At the time of visit the eastern crosscutting part of the tunnel and its connection with the old workings and stopes at the west, also a part of these workings, were accessible, but the shaft and the two levels turned from it were not.

ECONOMIC GEOLOGY.

Character of country rock.—The ground occupied by the Woodside property is entirely in the Park City and Weber formations. About two dozen prospect tunnels with the surface ditching and prospect shaft and the excellent cut for the main road, together with the underground exploration, afford unusually complete data on its stratigraphy. This work shows massive homogeneous dense Weber quartzite, passing upward through a transition sandstone and calcareous shaly beds into a succession of limestone beds with intercalated sandy members which constitute the basal part of the Park City formation. The calcareous members in the lower 30 to 70 feet are generally the ore-bearing beds, particularly one immediately overlying a quartzite or quartzitic sandstone. Special private work was thought by some to have revealed two other desirable limestones overlying quartzitic members, but this interpretation requires an apparently excessive thickness of beds and involves structural difficulties. No intrusives were observed in this ground.

Structure of country rock.—The prevailing dip of these beds is 10°–25° W. This dip is locally changed, however, by dragging on fissures, so that in some places it rises to 60°, and in other places, as in the rear of the shaft house, it is notably turned or even reversed. These beds are traversed by a system of fractures striking N. 30°–55° E., which commonly stand nearly vertical or dip northwestward. Two of the most prominent of these fractures are distinctly traceable on the surface, one of them passing through the main shaft. Minor ones parallel to them are also seen east of the shaft by the roadside. The cropping of the contact of the Weber and Park City formations has suffered displacement on these major faults, as may be seen in a dipping of the inclined block, immediately south of the Woodside shaft. North of this ground a fault zone trending eastward toward the Alice workings is seen to have caused a horizontal displacement of about 50 feet to the east on the south side. Underground in the Woodside mine many northeast-southwest fissures have been cut. Detailed sections along the lines of the principal development indicate that the displacement along many of these faults is down on the north, the probable offset in one being 200 feet. Displacements in the contrary direction are encountered, however, two of these apparently amounting to a drop of 100 feet each on the south side and another to a drop of 125 feet. The displacements are usually of normal character, or gravity displacements, but one shows an overthrust of at least 100 feet.

Ore bodies.—The ore bodies thus far discovered occur in the western part of the property adjoining the Silver King ground, though considerable crosscutting and careful prospecting has been carried on in the ground directly accessible from the shaft. The main body is the great shoot, which was followed by lessees from the surface northwestward and down into Silver King ground. It was a pod-shaped shoot, which formed along a limestone bed within a strong fracture zone and dipped gently northwestward. As a rule this and the other shoots developed in this immediate vicinity lie along calcareous beds in or adjacent to fracture zones in the lower 50 to 60 feet of the Park City formation. Detailed studies made by those directing the prospecting were believed to show that within the lowest portion ore formed in these limestone beds, each of which was underlain by a sandy or quartzitic member and the main or highest one being also overlain by quartzite. The calcareous member replaced was a fine-grained dark dense bed. The ore beds or lenses ranged from 2 to 40 feet in thickness. The clearest case observed, that at the Carey incline, showed ore in beds through a 4-foot member and in vugs, pencils, and stringers out from these parent bodies. At a lower horizon the ore was formed in a soft sandy member. In the eastern part of this property some fractures show staining, but no ore body was observed.

Character of ore.—The ore seen on the walls of the old stopes was made up of copper carbonates and lead carbonate, sulphate, and sulphide. That mined by the early lessees is understood to have been lead-silver ore of the character of the famous rich crude ores of the Silver King mine. A significant gangue mineral found in the ore at the Carey incline is fluorite, both massive and semicrystalline. It occurs in lenses an inch thick in the limestone and in the ore lying accordant with the bedding in each bed. It appears to be contemporary with the ore, though proof of this could not be found.

ALICE SHAFT.

The Alice property is situated in Woodside Gulch on the outskirts of Park City, about 1,300 feet west of the Ontario mill. At the time of visit desultory prospecting was being carried on in the massive Weber quartzite, which outcrops above the road at this point in bold cliffs, with a view to finding silver-lead ore in fissures. A shaft which descends immediately beside the road was reported to have reached a depth of 500 feet. From the bottom a drift was stated to have been driven northwest to a north-south fissure, which was opened for 200 feet along its strike, and a drift to have been pushed 400 feet beyond the fissure, cutting a barren breccia zone. Other prospecting reported is a tunnel on the east side of the road, which was stated to extend 90 feet in quartzite, and an inclined shaft of 90 feet with northwest and southeast drifts turned from the bottom. The managers stated that no shipments had ever been made from this property and that no ore had yet been found.

EASTERN SLOPE.

GENERAL GEOLOGY.

Surface features.—The eastern slope, the easternmost of the three natural divisions of the Park City district, is a remarkably regular topographic unit. From the north-south divide that separates Summit and Wasatch counties and turns the eastern from the northern and southern drainage stretch long, slender spurs sloping generally eastward and walling intermediate canyons. The regularity of the southern spurs, however, is somewhat interrupted, for the main canyons between them receive important laterals whose branches incise the north and south faces of the spurs. The gulches on the north of McHenry Canyon—Pocatello, McCune, and Drain Tunnel—are of the linear type; and the canyons on the south—Glencoe, Cottonwood, and Durey Hollow—are more arborescent.

Subdivisions.—The geology of the eastern slope in its broader aspects is likewise regular. The area is occupied by several formations, from the Weber quartzite to the Thaynes formation, which slope generally toward the east at a moderate angle. These beds have been subjected to faulting, intrusion, and extrusion, which have locally interfered with the regularity of their geologic aspect, especially in the central third of the eastern slope. This area, bounded on the north by the McHenry fracture zone and on the south by the similar Cottonwood fault, is one of three geologically distinct areas into which the eastern slope is naturally divided—a northern, slightly disturbed sedimentary area; a central, much intruded quartzite area, and a southern area containing both igneous and sedimentary rocks.

Northern area.—The northern area presents the Park City, Woodside, and Thaynes formations in regular order, inclined generally to the east at a small angle and occupying the western half of this particular area.

The Park City formation walls the east side of Deer Valley with its craggy edges and slopes eastward toward the Woodside shale, under which it disappears, as may be seen on the Heber road, half a mile east of the gap. North of the road it seems to pass beneath the red shale in a normal manner at an angle of 10° to 35°, but on the south it steepens, breaks, and finally seems to abut against the red shale on the plane of a fault and is not continued eastward until it has dropped perhaps 200 feet below the surface.

The Woodside formation, composed almost wholly of shales of a prevailing red color, is well exposed north of the Heber road, where it describes a conspicuous arch over the barren

slope on the north, crossing the gap and disappearing in the next gully. In its course it encounters an indistinct fault which apparently offsets it a few hundred feet, crumples it slightly, and forms, from the summit of the ridge northward, its eastern boundary. Along this line of disturbance the beds were seen to dip as steeply as 70° E., but elsewhere their inclination is moderate and where they pass beneath the Thaynes formation 30° may be taken as the average. South of the road this dislocating fault forms the northwest boundary of the shale and reduces it to an unusually thin band until it reaches the divide and broadens out against the Frog Valley fault. In this stretch it is folded and shows many unusual dips to the south and west. Here the color of the shale begins to change, passing from a deep red through mottled reds and greens to a light greenish drab, and with this new phase apparently well fixed it continues southward, bounded on the west by the Frog Valley fault and the dense Weber quartzite, heading Pocatello Gulch, and crossing the ridge into McHenry Canyon, where it is entirely cut off by the McHenry fault. In this course the unusual dips existing at the head of Frog Valley and Pocatello Gulch disappear, and the beds return to their customary easterly dip, passing beneath the limestone of the Thaynes formation at an angle averaging 25°.

The Thaynes formation, like the red shale, occurs as a north-south belt of gray calcareous sandstone and blue limestones extending the full length of the northern area and ending against the McHenry fault. This belt, though in general moderately inclined to the east with its upturned edges incised by the main streams, has suffered considerable disturbance. Its average eastern dip of 25° has been interrupted by buckling and folding. Consequently the strata in places, as in the locality between Pocatello Gulch and the Heber road, stand on end in monoclines or are overturned in more complex folds. In these folds the dips swing around the compass from east through north to northwest and west with widely varying inclinations.

In addition to the folds, faults have also combined to disturb the regularity of the beds. The faults belong to two main systems—the east-west, of which the McHenry fault is the type, and the north-south, of which the Frog Valley fault is the principal one. The Frog Valley fault, after inclosing an elevated lens of limestone of the Park City formation, branches toward the east. Hence, although the main fault probably continues along the eastern escarpment of Deer Valley, forks of it cut northeastward across the formations causing the dislocations and minor crumpling in the Woodside shale above noted. The McHenry system, on the other hand, belongs to a linear type of fracture and is accompanied by parallel fissures in the beds north of McHenry Gulch and in the quartzite on the south. The extension of the main fissure westward is indistinct but probably forms a part of the general Ontario system. The same uncertainty surrounds the meeting of the McHenry and Frog Valley faults, for their junction is in a deep gulch, well wooded, and largely filled with wash, so that the evidence as to the relative age of these master faults is concealed. The limestone of the Thaynes formation and the red shale have been offset, particularly at the head of Drain Tunnel Canyon, by a branch of the Frog Valley fault, but farther south along the main fault the shale abuts against the quartzite. The McHenry fault likewise drops the Thaynes beds shoulder to shoulder with the quartzite on the south. The low spur between this canyon and Pocatello Gulch also shows evidence of deformation on its eastern slope, for beds which from paleontologic evidence seem to belong several hundred feet above the limestones on the crest of the ridge have been dislocated and lowered into juxtaposition with the limestones. Normally these two series are separated by a few hundred feet of red shale, below which the determining fossils have elsewhere never been found, but in this area no red shale is known except the small portion overlying the higher beds along the Heber road. This unusual feature indicates either that a fault has entirely hidden the thin red shale or that the fossils which normally occur above the thin red shale occur here below the shale, making the red shale on the Heber road a fragment of the thin shale above mentioned. Finally the master faults of all, one following McHenry Canyon from head to mouth and the other running through Frog Valley, sever the entire series of formations from their normal continuation southward and westward and form natural boundaries to the northern area.

Persistent intrusions and broad extrusions of igneous rocks have aided to complicate the structure of the several formations. Thus dikes of diorite porphyry cross the mouth of

Pocatello Gulch, head McCune Hollow, and then thin out westward along the crest of the ridge, cutting limestone of the Thaynes formation and in a few places surrounding portions of it. Lapping possibly against the old surface of these dikes, certainly against that of the inclined sediments, lies the broad sheet of andesite which occupies nearly the entire eastern half of this area. Its western boundary is marked by protruding hills of the ancient surface around which it wraps and from which it extends in eastward dipping layers or flows far out into the valley, even across Weber and Provo rivers. Most of these islands, as they might be called, are composed of metamorphosed sediments, but one of considerable extent near the northern border of the district seems to consist partly of an igneous rock apparently older than the lava, being probably diorite porphyry. But this expanse is not all andesite at the surface, for a broad apron of alluvial gravels wraps around the older slopes of the andesite plain and conceals it for several square miles.

Thus the northern section of the eastern slope exhibits in its western half the beveled edges of three formations (Park City, Woodside, and Thaynes), dipping moderately to the east with their upturned ends incised by eastward-flowing streams. The regularity of these beds, however, has been broken by block faulting along east-west and north-south lines, light though complicated intrusion, and blanket-like extrusions covering the lowlands.

Central area.—South of the northern area just described lies the intermediate area, cut off on the north by the McHenry fault and bounded on the south by the Cottonwood fault and its western projection. The sedimentary rocks of this area, except a small cap of the Park City formation on the outer margin of the district, belong exclusively to the Weber quartzite. This series maintains the usual easterly dip of this section, but at the somewhat increased angle of 55°. Some localities show other inclinations, but the range is not great. The best examples border McHenry and Glencoe canyons and the head of Cottonwood Canyon; for instance, the beds south of the Hawkeye mine slope 20°–70° N., and those on the knob east of the Glencoe mine and on that north of the Valeo dip 45°–65° NE. This central area is characterized not only by rocks largely of one formation, the Weber quartzite, but also by the fact that the continuity of these beds is broken by extensive and irregular igneous intrusions. The igneous magmas have metamorphosed the bordering sediments, especially the intercalated limestones, broken and offset the quartzite series, torn off isolated bodies and invaded the whole mass with ramified dikes and sills. The metamorphism has rendered the identification of the intercalated limestones difficult either by stratigraphic or paleontologic means, and therefore the amount of actual offsetting can not be stated with certainty. The limestone, however, is probably correlative with the similar beds on the north and south and perhaps with those a mile to the the east and in Glencoe Canyon. There is little doubt that the last two at least belong to the same bed which has been offset a mile on a north-south line. Isolated bodies or horses of limestone, are particularly common along Cottonwood Canyon. These are not, however, limited to the limestone beds of the Weber quartzite but include numerous horses of quartzite alone separated by dikes. Dikes also cut the limestones, and narrow extensions of the same igneous mass seem to protrude into Big Dutch Pete Hollow. In the upper half of this valley, however, the contacts of the rocks were concealed by heavy float, well grassed over and thickly wooded. Hence although diorite porphyry occurs in this locality, its boundaries can not be accurately traced.

That the sedimentary continuity has been as much affected by intrusions and faulting is doubtful. Only a few minor fissures were observed, either on the surface or in mines. Of these the largest and commercially the best known is the east-west fissure of the Glencoe property. Without some conspicuous datum bed, however, surface indications of faults in homogeneous rocks like diorite porphyry and quartzite are difficult to detect, especially under vegetation. Hence some minor dislocations may have escaped notice. The McHenry fault, bounding this area on the north, arises somewhere on the southern border of McCune Hollow, and seemingly follows the contact of the diorite porphyry and sediments westward across the mouth of Pocatello Gulch into McHenry Canyon. It continues westward along the bottom of the canyon, bringing the Thaynes and Woodside formations into juxtaposition with the Weber

quartzite, and finally disappears in the diorite porphyry mass at the divide. The Cottonwood fault on the south is in many respects similar to the McHenry fault. Issuing from the andesite sheet on the east, it enters the district a mile north of the southeast corner and continues westward, bringing the Woodside shale and Thaynes formation against the Park City formation and Weber quartzite, and disappears in a mass of diorite porphyry somewhere west of Cottonwood Canyon. Finally the rocks of the central area, sediments and intrusives alike, are flanked on the east by that great andesite flow which blankets an old surface for many miles. The edge of this body within the district mapped is partly obscured by the broad expanse of outwash gravels that extends far up the ridge north of Glencoe Canyon, crosses toward the southeast, and covers the easy slopes bordering the lower course of Big Dutch Pete Hollow. On the southern slope of the hollow the gravels waste away and the weathered surface of igneous rock above was so finely powdered that it could not be determined. But as andesite lava is found at this elevation both on the north and on the south, it seems likely that this, too, may be disintegrated rock of the same flow rather than diorite porphyry.

Southern area.—South of the central area just described the district is terminated on the east in a third geologic unit lying south of the Cottonwood fault and its westward projection. This area is characterized by a section of beds analogous to those of the northern area, but compressed into very small compass by an immense intrusive on the west. Consequently, although the beds maintain the general directions of strike and dip common to the eastern slope, their dip is steeper, averaging 60°. Thus a part of the Weber quartzite with an intercalated limestone extends from Cottonwood Canyon to the southern margin of the district as a broad belt, forming the twin hills between Cottonwood Canyon and Durey Hollow, and sloping toward the east at angles between 50° and 80°. Similarly limestone of the Park City formation occurs in a narrow belt along the eastern slopes of the twin hills, notched by gullies, and conformable in dip with the underlying quartzite. The northern extension of this limestone, however, is interrupted by intrusions of diorite porphyry and hidden by a covering of stream gravels. The Park City formation at this point is strikingly thinner than in the type section in Big Cottonwood Canyon. Likewise the overlying Woodside shale shows a distinct thinning in this locality. Though deformation may explain this difference to some degree, it is believed to be due partly to eastward decrease in deposition. The red Woodside shale is less regular in occurrence than the Park City formation. Although it normally overlies the Park City and is somewhat similar in dip and strike, as well as in extent, south of Cottonwood Canyon, north of the canyon it is disturbed by the Cottonwood fault, against which it ends and by which it is upturned into a syncline that pitches southeastward with one limb resting against the Weber quartzite. In this limb, therefore, the usual moderate easterly dip of the beds has been steepened and turned nearly a quadrant, so that the shales stand almost vertical and trend east and west. The south end of the red shale, especially its extension south of Cottonwood Canyon, is largely hidden by outwash gravels, so that it is best exposed in deep ravines but scarcely shown on the intermediate ridges. The Thaynes formation is in manner of occurrence a duplicate of the red shale; the south end is covered with gravel, the central part along the northern slope of Cottonwood Canyon shows normal steep easterly dips, and the northern border is overturned and brought to an east-west trend parallel with Cottonwood fault. Thus at the surface the Thaynes formation presents a triangular area, which descends eastward beneath the broad andesite flows that enter the extreme corner of the district.

This series of beds, comprising the Park City, Woodside, and Thaynes formations normally upturned toward the west and once connected with like beds on the north, has, as already suggested, been profoundly affected by faulting, intrusion, and extrusion. The faults generally fall into two groups, the more important trending east and west and the minor fractures north and south. The Cottonwood fault, which bounds this area on the north, is the most far-reaching in its effects. To it is due the upturned fold along which not only the soft beds of the Woodside shale but the stiffer limestones of the Thaynes formation stand on end or dip slightly northward. A minor fracture of the same system cuts the sediments on the south side of Dutch Hollow, but the other small fractures of the area belong to the north-south system and occur chiefly on the

lower slopes of Cottonwood Canyon. Perhaps contemporaneous with the faulting and probably causing it is the great intrusion of diorite porphyry west of the sedimentary series. The combined effect of the two powerful agents is that the beds have been pushed eastward nearly a mile and a half, and the space thus vacated is now occupied by the intrusion itself. This space is marked by long stretches of porphyritic diorite surrounding and supporting stray blocks of the sedimentary beds. These blocks belong chiefly to the Weber quartzite and consist of quartzite and intercalated limestone. Both rocks are so much metamorphosed, as are also the contact of the main series on the east, that no fossils remain as a means of correlation. The same cause has obscured the sedimentation of the beds so that their inclinations are seldom measurable. Limestone blocks in Dutch Hollow, however, especially the one farthest west and the one on the divide from Cottonwood Canyon, show a fairly definite dip toward the southeast.

Finally, after the sedimentary series was thus affected by faulting and intrusion, the formations far to the east, including a part of the Thaynes within the district, were covered by an extrusion of andesitic lava. Thus within this particular area the andesite wraps around the rocky slopes of the Thaynes formation and occupies the extreme southeast corner of the district. Its actual contact with the sediments, however, is concealed southeast of Cottonwood Canyon by an apron of alluvial gravels similar to that observed in the central and northern areas.

DUREY HOLLOW AND DUTCH CANYON.

GEOLOGIC FEATURES.

The sediments found in Durey Hollow within the area mapped appear to belong to the Weber quartzite. They are, however, fragmental, occurring as irregular tongues and horses in a large intrusive mass of diorite porphyry. Where Durey Hollow heads in this rock there are more or less isolated areas of Weber quartzite. Farther east, however, horses of limestone predominate, decreasing in size until the main body of upper Weber quartzite southeast of Cottonwood Canyon is reached. These horses appear to be portions of the limestone intercalated in the Weber quartzite and therefore belong to the same formation. The lower course of Durey Hollow, shown along the margin of the map, is still in diorite porphyry, but it crosses the contact a little farther south.

The structure of the sedimentary areas is somewhat obscured by metamorphism, but the observed dips are generally 60° to 80° E. or SE. and the exceptions are limited to the intermediate quartzite horse at the head of the south branch, whose strata slope toward the north, and the quartzite mass occupying the central south side of the hollow, in which the beds dip toward the south.

In addition to the isolation caused by intrusions the sediments have undergone minor brecciation and dislocation. The most prominent example is the fissure between the quartzite and limestone that compose the horse on the south side of Durey Hollow. Though some other fracturing was seen, it was largely confined to breccia zones, one of which in the limestone horse south of the divide between Durey Hollow and Cottonwood Canyon is extensive and somewhat mineralized. In a few places the contact of porphyry with the sediments displayed brecciation, and at one point it was mineralized.

No ore of commercial value has been found in Durey Hollow, but many tunnels have been driven on surface indications and these have opened mineralized zones. The typical mode of such occurrences is that of breccia zones along planes of fracture. Not all such zones, however, are mineralized, and the best examples of the occurrence are in the limestone horse south of the Cottonwood Canyon divide and at the easternmost point of the quartzite tongue crossing the head of Durey Hollow. These zones were visible for only a few feet and no definite direction of the fracturing could be ascertained.

COPPER QUEEN TUNNELS.

The Copper Queen mine is situated in Dutch Canyon near its head, high on the northern slope. The workings consist of two short tunnels, one 50 feet above the other. The rocks in the vicinity consist of diorite porphyry surrounding and invading a tongue of Weber quartzite

and severing portions of it. The contact, which is very steep and appears to be somewhat crushed, is cut 50 feet from the mouth of the lower tunnel and at the portal of the upper tunnel. The chief zone of mineralization, which is along the contact, is exposed in the upper tunnel. The larger part of the mineral, however, consists of minute crystals of magnetite mixed with calcite. Much of it is browned by iron rust, and in places considerable quantities of a green mineral, which proves to be malachite, are scattered through the ore.

BLUE LEDGE PROPERTY.

The Blue Ledge ground is located in Dutch Canyon beyond the limits of the district mapped, in the southeastern part of the southern area. It is an old location and considerable work has been done on it, including a new tunnel, an old incline, and a long recent tunnel on the south side of the creek; also an old lower tunnel on the opposite side. The ground includes a body of quartzite on the north side of the creek and considerable limestone on the south side, which has been cut and in places highly metamorphosed by an extensive body of coarse porphyry.

A new tunnel driven 60 feet in decomposed porphyry cuts iron-stained material at its face. The old incline sunk in the spur on which the property is situated descends for 100 feet at an angle of 90° through altered calcareous sandstone bearing hematitic stains. The main tunnel, vertically 300 feet below, is in the main porphyry mass that forms the ridge and in highly marmarized cherty limestone adjacent to the intrusive. It cuts an irregular north-south fracture zone in metamorphic limestone and a clean slip contact between the intrusive and the marble. The old tunnel, run in the early eighties, extends N. 70° E. for 500 feet in quartzite that dips northeast and shows crushing and bright-red iron staining. No ore was observed.

LITTLE KNUTSFORD TUNNELS.

The Little Knutsford property is situated in the southeast corner of the district, in a branch of Dutch Canyon. The workings include an incline near the top of the ridge 60 feet deep, a 30-foot shaft, and below, at the creek level, a tunnel about 700 feet in length.

The surface shows porphyry inclosing horses of marble and of quartzite, the whole being cut by northeast fissures. The incline follows, at an angle of 55° N. 63° E., a contact between coarse porphyry and black shaly sandstone without opening ore. The shaft is on a northeast fracture zone in quartzite and exposes some malachite. The main or lower tunnel extends in a general southwest direction beneath these workings, heading for the outcrop of marble on the ridge above. The mouth and the face of the tunnel are in coarse porphyry; along its course dark carbonaceous limestone is cut by porphyry, and the whole is broken along northeast-southwest and northwest-southeast fissures. Slight mineralization was noted on some northeast slips.

PINE AND COTTONWOOD CANYONS.

GEOLOGIC FEATURES.

The rocks in Cottonwood Canyon include a wide range of the sediments of the eastern slope. From the Weber quartzite with its intercalated calcareous beds the series extends upward into the Thaynes formation. This section as a whole is upturned to the west with an easterly inclination averaging 60°, but this general structure is distorted locally by folds, which, except along the Cottonwood fault, are of little consequence. Into the beveled edges of these beds Cottonwood Creek has incised its canyon and, flowing down the valley over the various formations in stratigraphic order—the oldest (lower Weber quartzite) at its head, the intercalated linestones cut by diorite porphyry at the Valeo mine, the upper portion of the Weber quartzite next, and lastly the Park City, Woodside, and Thaynes formations opposite the East Valeo shaft—leaves the district mapped over disintegrated flows of andesitic lava. This regularity is sharply broken on the east side of the canyon, where the Cottonwood fault is the main dislocating fissure, and elsewhere by minor north-south and east-west fractures. The main fault brings the Woodside shale shoulder to shoulder with the Weber quartzite, the Park City formation being lowered out of sight, and in so doing it turns the general north-south trend of the softer beds south of the fault into an east-west strike

In this series of faulted and intruded rocks ore has been found in only a single bed—intercalated limestone in the Weber quartzite. Here it occurs in irregular replacement bodies roughly parallel with the bedding. Other mineralization on the Cottonwood fault is confined to fissures in the adjoining country rock.

VALEO MINE.

The Valeo mine is situated on the southeastern slope of Bald Mountain near the head of Cottonwood Canyon, about 4 miles southeast of the Ontario mine and 3 miles south of the Hawkeye-McHenry. This is the principal property on the Eastern Slope. After the depression of 1893 the outlook for silver-lead mines began in 1895 to seem more promising and encouraged new work. The years immediately following were the most active epoch in the history of this mine. In 1896 excellent ore was found on this property, and in August of that year some of the ore was shipped and surface improvements were made. A month later a new vein of high-grade ore was cut which on opening further was found to improve steadily in quality. The year closed with new ore developments of much value and in January, 1897, it was stated that a body of high-grade ore 5 to 10 feet wide in a fracture had been exposed for a length of 135 feet.

In the fall of 1898 the property, comprising some 16 claims, was taken over by prominent mine owners to be opened systematically and operated on a large scale. After working out the main ore body they did some development work, but the results were deemed insufficient to warrant much outlay at that time. Since then only desultory work has been carried on, and at the time of visit, late in 1904, the property was inactive.

This ground has been opened by three tunnels, which enter the south wall of the canyon one above another and extend in a westerly direction, the upper for 200 feet, the middle (or 400-foot level) for 1,000 feet, with 1,500 feet of north-south workings, and the bottom (or 600-foot level) for 1,200 feet. The upper tunnel is connected with the middle one by inclined winzes on the ore shoot, with short intermediate levels. From the lower tunnel a little raising and sinking was done.

The property lies in an area of Weber quartzite which is much broken and interrupted by an extensive mass of diorite porphyry. At this point the quartzite contained intercalated lentils of limestone and in the course of intrusion portions of this limestone, as well as small horses of the quartzite were broken off from the main mass and engulfed by the porphyry. A large mass of this limestone, highly metamorphosed and mineralized, outcropping for half a mile in length northwest to southeast and one-fifth of a mile in width, then succeeded by porphyry, forms the base of mining operations.

Underground the tunnels cut metamorphosed mineralized limestone and coarse diorite porphyry. In general the main body of porphyry, which is west and north of the limestone and apparently underlies it on the northwest, is entered by the tunnels after traversing the metamorphic marble. The main body of the limestone strikes about N. 75° E. and dips 60°–70° NE. Offshoots from the main porphyry mass, in the form of irregular dikes and sills are found cutting the marble on all levels. The porphyry is of the coarse dioritic variety and the limestone is mostly marmarized or otherwise altered.

This country rock is cut by many fissures, which, though complex and irregular, seem to fall into two main systems—those trending N. 40° E. and dipping northwesterly and those trending northwest and dipping northeast with the beds. Intersections of these fissures tend to show that the former, those trending northeast, are later than the strike fissures, and as both systems cut the porphyry, they are later than it.

Ore has been found on every level, but it has been so cleanly stoped and is so highly oxidized that observations were necessarily based on the chambers remaining and the limonitic residue. On the upper tunnel (100-foot level), which is understood to have been the chief source of ore, the chambers seem to show that the main ore body occurred roughly along beds in the metamorphic limestones that were much disturbed by fracturing and on either side of a wedge of porphyry. Uniting with this main ore zone are transverse breccia zones lying roughly along

porphyry contacts. Ore has been stoped from these zones. The main stope observed on this level was 3 to 6 feet high and 30 by 30 feet in section and, according to authentic statement, the ore body was followed 300 feet down to the level of the middle tunnel. The prevailing walls are highly limonitic, hematitic, and manganiferous metamorphic limestone. In general the shoots lie along zones of breccia in limestone adjacent to porphyry.

On the middle tunnel the beds are highly ferruginous and oxidized. The only ore found was reported to have been taken from a fracture trending east and west along a contact under metamorphic limestones and over porphyry. The lower tunnel opened much oxidized limonitic material adjacent to decomposed porphyry and at one point a strongly shattered zone roughly coincident with the bedding, from which, it is said, a large body of limonite was taken. No other metals were seen on this level.

The ore, which thus appears to have been taken chiefly from a shoot between the upper and middle tunnels, was an oxidized silver-lead ore. Around the walls of the stopes at the time of visit the most striking and abundant feature was limonite of many varieties, particularly the light ocherous dusty variety and the darker porous spongelike variety. Mr. Woolsey found ore replacing the cement or matrix of a limestone breccia. The only occurrences of ore observed, however, were of malachite as a thin coating upon walls of cavities in porous oxidized limonitic and manganiferous decomposed limestone.

The metallic contents of the ore reported during the period of active mining were high. Thus from a new vein cut in 1896, 29 per cent of copper, 10 to 14 ounces of silver, and $6 to $8 in gold to the ton were obtained, and a little later practically these same figures were given as the average tenor of the ore.

The isolation of this mine and its distance from smelters were doubtless the reasons for erecting the small smelter at the mouth of the middle tunnel. A plentiful supply of suitable iron and limestone favored the undertaking. Some slag still remains as a witness to its operation, but nothing authentic was learned about the results obtained.

EAST VALEO MINE.

The East Valeo mine is situated in Cottonwood Canyon, on the northeast slope a short distance below the main forks. The workings consist of a shaft reported to be 150 feet deep, with a crosscut of 150 feet, and there are short tunnels near the bottom of the canyon west of the shaft. The rocks surrounding the shaft belong to the Weber quartzite, but this is cut off on the north by diorite porphyry and on the south by the Cottonwood fault, which brings the Woodside shale opposite the Weber quartzite. The shaft was inaccessible at the time of visit, but, to judge from the dump, it passes from quartzite into porphyry and thence into red shale, which is said to lie in the bottom. Hence the shaft seems to penetrate the plane of the Cottonwood fault, and consequently the fault plane appears to dip to the north. Of the tunnels west of the shaft which lie near the contact one is in limestone and the other in porphyry. The Cottonwood fault must pass near by, but the geologic relations at this point are obscured by float. The limestone is pyritized, but no ore was seen. The croppings near the shaft show limonitic stains on east-west fracture zones.

ADLA CONSOLIDATED TUNNELS.

The Adla Consolidated claims are situated in the south fork of Cottonwood Canyon a few hundred feet above the mouth. The property is developed by two short tunnels low on the south slope. One is in scarcely 10 feet, but the other extends west for 85 feet. The irregular contact between the main mass of diorite porphyry on the west and the Weber quartzite on the east passes between the two tunnels. Hence the smaller eastern tunnel lies only in quartzite, dipping generally to the east, whereas the western tunnel cuts porphyry and a small horse of limestone and quartzite. The western tunnel exposes some slight north-south fissures, but neither shows any ore.

SMITH TUNNEL.

The Smith property is situated in the branch of Cottonwood Canyon that enters from the north near the main forks. The workings consist of a tunnel over 300 feet long, with a crosscut running north of nearly the same length. The property lies in an area of diorite porphyry, which holds horses of quartzite and limestone of various sizes. In fact, just east of the tunnel is a large remnant of Weber quartzite apparently surrounded by diorite porphyry. The tunnel enters on diorite porphyry and reaches the edge of this horse at 300 feet. The crosscut is entirely in porphyry. No mineralization was seen save veins of calcite and stains of iron oxides coming perhaps from pyrite in the porphyry.

SUSIE G TUNNEL.

The Susie G tunnel is situated at the very head of Cottonwood Canyon, just under the divide. It extends southwest for 175 feet and has a 30-foot crosscut running west, besides an incline of 15 feet and a winze of about 100 feet. The rocks at the surface indicate a limestone horse surrounded by diorite porphyry. The workings are confined largely to the horse, which underground becomes a soft calcareous sandstone dipping 40° SE. In places it is very considerably fractured and appears as if the fragments were cemented by igneous rock into a diorite breccia. Mineralization is limited to stains of copper, iron, and manganese on the limestone.

ROSEBUD TUNNEL.

The Rosebud tunnel is situated at the extreme head of Cottonwood Canyon, just under the divide. It extends due west into the slope for 120 feet. The surrounding rocks are diorite porphyry holding horses of limestone. In the tunnel only igneous rock occurs, and the larger part is the ordinary porphyry of the country, but there is a 45-foot dike of a finer diorite porphyry of later age. The outer contact occurs 65 feet from the portal and displays the flow structure and selvage of a younger intrusion. Slight northwest fissures cut the rocks, but no mineralization except by iron oxides was observed.

GLENCOE CANYON.

GEOLOGIC FEATURES.

In Glencoe Canyon and the area extending thence eastward to the margin of the district mapped the rocks are not much varied in character. For the most part the sedimentary rocks are limited to the Weber quartzite and scattered exposures of its interbedded limestone. Across this mass a broad dike of diorite porphyry extends from Cottonwood Canyon northwestward to McHenry Canyon, sending out tongues and spurs into the adjoining beds. Finally an apron of outwash gravels covers the lower parts of Glencoe Canyon and the valley on the east, except in a small area near the mouth of the latter valley where the andesite lava obscures the bedded series.

In general the structure is that of beds inclined to the east or northeast at about 55°. These beds have been cut by igneous intrusions and broken by perhaps contemporaneous fracturing and faulting. There are numerous minor faults belonging to two main northeast-southwest and northwest-southeast systems, but the most prominent fracturing seems to occupy an intermediate east-west course. The Glencoe fissure, for example, is a strong east-west fracture, which may extend to the east far beyond the mine and account for the half-mile offset in limestone intercalated in the Weber quartzite. While mineralization in this area is widely distributed in both fissures and country rock, especially diorite porphyry, it has not formed concentrated bodies of commercial importance except in the Glencoe mine. Here the deposit takes the form of an enriched fissure having a general east-west trend.

GLENCOE MINE.

The Glencoe mine is situated on the east slope of Bald Mountain, in Glencoe Canyon, about midway in its length, and near the center of the large intrusive of diorite porphyry that crosses the canyon at this place.

This property was located in the early seventies by Messrs. Cook, McCune, Cupit, and Braun. Under the direction of McCune the upper tunnel with crosscut was run, but without cutting ore. The property then passed into the hands of the Glencoe Mining Co., under whose ownership most of the shipments from this mine were made. Near the close of 1882 the main tunnel had been cut 450 feet on the vein, from which ore had been taken to the amount of 200 or 300 tons. This ore is said to have assayed 40 to 50 per cent of lead and 40 ounces to the ton in silver. During the succeeding year several hundred tons of ore, said to be of low grade and refractory, were stored on the dump. For the following five years, ending with 1888, there is a blank in the record, but during the period from 1889 to 1892 the mine reached its highest prominence. In the first year of this period it was taken over by a new company, having a capital of $2,500,000. Ore continued to be plenty, some new strikes were reported, and the new management decided to erect a concentrator of 100 tons capacity. This was completed in 1891, and was the third concentrator in the camp. The reduction was 4 tons to 1, and the concentrates are reported to have assayed 25 ounces to the ton in silver, 50 per cent of lead, and $3 to the ton in gold. During this year the stock rose from $2.50 in March to $5.50 in August, approaching very closely the price of Anchor stock at the time. Some carloads of the concentrates were shipped, but the ore grew zincky, and in 1892 the concentrator was hindered somewhat for lack of water. This was the close of the period of prosperity. In 1893 the mine stood idle, and the machinery was attached and sold by the marshal to pay an indebtedness thereon of over $11,500. In 1895 the machinery was removed to Bingham, Utah, and meanwhile the completion of the Ontario drain tunnel had largely depleted this property of the water used for milling. In the later nineties and early part of the decade following the mine stood practically idle, but it was examined from time to time with a view to consolidation with surrounding properties for more economical exploration. In 1904, however, it was leased under bond, and work was resumed, the mill being renovated to treat the ore on the spot. These operations were interrupted by the death of the principal party, and for the next few years the mine is understood to have remained closed. This property was taken over by the Adirondack Mining Co. in 1908, a 150-ton mill was erected at the mine, and other preparations were made for active operation.

The property is opened mainly by two tunnels, one above the other, which are connected by both a winze and a chute 154 feet deep. The upper or discovery tunnel has two portals, the branches from which meet a few feet underground. It connects at a point 130 feet from the portals with the lower tunnel and extends nearly west into the west side of the canyon for a distance reported to be nearly 700 feet. The lower tunnel enters the east side of the canyon several hundred feet below the upper tunnel, extends southward into the hillside for 600 feet, thence turns sharply westward and runs for 1,200 feet, passing beneath the canyon and the discovery tunnel, and finally forks, one branch extending northwest 200 feet and the other southwest 100 feet. On the main drift, about 800 feet from the angle with the portal part, occur the winze and chute, which connect this drift with the discovery tunnel above. Along this main drift also there are several stopes overhead, and in the upper tunnel a small slope near the chute reaches the surface.

The rocks cropping near the mine are largely diorite porphyry, being part of the large intrusive that crosses the canyon here through the Weber quartzite. Quartzite, however, occurs on the slope above the discovery tunnel and crosses the canyon some distance farther up, probably with the northeast dip common at the head of the canyon.

Underground at the time of visit the northwest fork of the main drift had penetrated marmarized limestone dipping 15° to 20° N. 25° E. All the other workings were then in diorite porphyry, but it seemed that the porphyry-quartzite contact should be intersected not much farther west. Insignificant fragments of limestone were met here and there in the porphyry near the forks of the main drift, but they were horses probably broken from the larger mass penetrated by the northwest drift, and this mass was probably a lentil in the Weber quartzite.

This country rock of diorite porphyry, except the main body of marble in the northwest drift on the lower tunnel and the few small limestone horses, is traversed by strong fissures

trending from N. 43° E. to N. 88° E. The main zone trends N. 55°–75° E., and dips steeply (60°, 72°, and 78°) toward the northwest.

The locus of the ore in this main zone, which was cut in the old upper tunnel a few feet from the mouth (trending N. 70° E. and dipping 80° NW.), and explored for a considerable distance, was cut on the lower tunnel at the proper distance farther in, allowing for dip after, and followed westward for many hundred feet. In general the ore lies in a fissure zone between porphyry walls and ranges in width from 6 inches to 6 feet.

Within this zone occurs a vein which pinches entirely out and again widens into definite shoots. One shoot observed on the upper tunnel was followed and stoped above this level, 60 feet, and below to the lower tunnel level, more than 150 feet. Two other shoots were said to have been cut in the upper tunnel in positions inaccessible at the time of visit, and at least three others opened on the lower level were observed. The prevailing pitch appeared to be toward the east and steep.

The ore in the surface parts of the main shoot appeared to be an oxidized lead-silver body, with accessory zinc in a limonitic gangue. On the upper tunnel some galena was left, and on the lower tunnel galena and resin zinc were seen, with some quartz gangue. At one place a 1-inch vein of pyrite and chalcopyrite occurs. On and within the porphyry walls was some disseminated pyrite.

J. A. C. TUNNEL.

The J. A. C. property is situated in Glencoe Canyon opposite the Glencoe mine. The workings lie on the west slope of the canyon and consist of a tunnel 500 or 600 feet long extending southwesterly. The outcrops near the tunnel are diorite porphyry, but a few hundred feet higher occurs the Weber quartzite. So far as observed the tunnel lies wholly in porphyry, but a cave-in 200 feet from the portal had closed the inner part of the mine to observation. Near the cave-in the tunnel intersects and follows a N. 70° E. fissure zone dipping steeply northwest. This zone shows about 8 feet of breccia carrying some metal between porphyry walls. Sinking and raising on this material uncovered a little ore. In the porphyry walls a little pyrite and chalcopyrite were noted. No ore has been shipped.

LEVARY TUNNEL.

The Levary tunnel is situated far up in Glencoe Canyon very near the Cottonwood Canyon divide. It is approximately 400 feet long and enters the west side of the canyon in a northwesterly direction but near the face turns to the southeast. It penetrates an area of Weber quartzite broken and extensively invaded by igneous intrusions. The quartzite contains its customary calcareous lentils, but they are truncated by diorite porphyry whose contact runs just south of the tunnel.

The tunnel enters on quartzite, but the beds gradually become more calcareous until near the face they have taken the character of marmarized limestone. Here and near the portal occur solution cavities in the limestone, which are filled with fragmental material. The beds dip generally 30° N. 70° E. and are but slightly disturbed by fissuring. Mineralization is confined to red and brown iron stains coating the detritus in the solution cavities. No ore was seen.

MARCELLA TUNNEL.

The Marcella tunnel is situated at the head of Glencoe Canyon a short distance from the Cottonwood Canyon divide. It is 55 feet long and enters the east slope of the canyon. The surrounding rocks are Weber quartzite containing limestone layers, but the tunnel is still wholly in quartzite float. No ore was observed.

HOMESTAKE PROPERTY.

The property of the Homestake Mining Co. is situated in Glencoe Canyon about half a mile from the mouth. The workings consist of a tunnel extending westward, a shaft 250 feet above the tunnel on the west slope of the canyon, a lower tunnel, which was inaccessible, and several lesser workings. The shaft is well constructed, with two compartments, and is estimated

to be about 130 feet deep, but at the time of visit was inaccessible. The rocks near the workings belong to the Weber quartzite. The dip of these beds is about 35° E. Exposures of soft thin-bedded limestones occur near the shaft, but east of it a blanket of gravels obscures the structure of the rocks and probably covers the contact of the limestone with the quartzite above. An intrusion of diorite porphyry cuts across the canyon and above the shaft but is largely concealed by gravels. Both workings have traversed the contact and end in the porphyry. The tunnel enters on quartzite, penetrates the underlying marmarized limestone lentil, and passes into porphyry, whereas the shaft begins on limestone and terminates in porphyry, having cut no quartzite. The general dip of the beds in the tunnel, as on the surface, is to the west. The porphyry in the tunnel showed considerable pyritization, but no ore was observed on the property.

EAST BLUE LEDGE TUNNELS.

The claims of the East Blue Ledge Mining Co. lie in Glencoe Canyon just below the forks and south of the Homestake property. Development has been carried on by means of short tunnels, all but one of which were inaccessible. This one enters the south side of the canyon and extends southeastward for 400 feet. The property lies on the contact of the intrusive diorite porphyry and the intercalated limestones of the Weber quartzite. These rocks outcrop near the tunnels and the sediments dip about 35° E. The accessible tunnel cuts 50 feet of limestone lentil near the portal and then continues to its face in the overlying quartzite. These beds are intersected by small northwest fissures, which the tunnel follows, and a few slight northeast fractures. The gouge of the former carries some pyrite, but with this exception no mineralization was observed. A caved tunnel farther up the canyon on the west side appears to be wholly in pyritized altered porphyry. No ore was observed.

HOWARD & REYNOLDS PROPERTY.

The property of the Howard & Reynolds Mining Co. is situated in Glencoe Canyon on the east slope below the forks adjoining that of the East Blue Ledge Mining Co. The ground is opened by short tunnels and a shaft 70 feet deep with a drift of 40 feet to the south. These workings were inaccessible. The rock in the vicinity as well as on the dumps was diorite porphyry somewhat decomposed and heavily impregnated with pyrite. No ore was observed.

BIG DUTCH PETE HOLLOW.

Big Dutch Pete Hollow lies next east of Glencoe Canyon, in the eastern portion of the mapped area. It marks a line of intrusion of diorite porphyry into Weber quartzite. East of the striking amphitheater at the head of the gulch extends a lens of the limestone intercalated in the Weber quartzite. In the lower part of the gulch the bed is buried beneath recent deposits.

SUNNYSIDE GROUP.

The Sunnyside group is situated in Big Dutch Pete Hollow two-fifths of a mile below the forks near the head of the gulch. The six claims of this group are opened by a tunnel, which penetrates the east side of the hollow but which was locked at the time of visit. To judge from the size and character of the dump, however, the tunnel may be 100 feet in length and the rock encountered, like that at the surface, appears to be wholly diorite porphyry. This is greatly decomposed, perhaps somewhat crushed, and commonly stained brown by the weathering of impregnating pyrite, but no other mineralization was observed.

GULCH CLAIM.

The Gulch claim is situated in Big Dutch Pete Hollow just within the boundary of the mapped area. The claim has been opened by a 50-foot tunnel running northwest and a raise to the surface at its middle point. It lies in an area of gravel fans through which protrudes an island of Weber quartzite, and in this the workings are made along a zone of northwest fissures. No mineralization was noted except slight coatings of iron oxides.

LOST BOULDER GROUP.

The Lost Boulder group is situated near the mouth of Big Dutch Pete Hollow just outside the district covered by the map. The group is developed by means of three tunnels—one caved in and inaccessible, another recently opened to a distance of 50 feet, and a third extending 230 feet southwest and having a crosscut of 75 feet to the southeast. The rock in the vicinity is largely Weber quartzite and the tunnels lie chiefly in this rock. No ore has been found.

WASATCH GULCH.

Wasatch Gulch is the westernmost of the succession of canyons that descend from Bald Mountain northeastward into McHenry Canyon. It lies in the main Weber quartzite area, which is here cut, however, by the main body of porphyry. These formations are traversed by east-west fractures, apparently sympathetic with the great McHenry fracture zone, which have been the field of exploration in this region.

WASATCH TUNNELS.

The Wasatch property is situated on the northeastern slope of Bald Mountain in Wasatch Gulch, 500 feet above and three-fifths of a mile southwest of its junction with McHenry Canyon. It was closed throughout the period of the present examination and little could be learned about it.

The original Wasatch property was located in the seventies, and the ground was opened and the principal development work was done in the eighties. It is stated that some promising ground was cut which, it was decided, merited opening at greater depth. Accordingly, in the early nineties a company was formed, which obtained control of the Wasatch ground and started operations toward driving a long deep tunnel from McHenry Canyon to explore the intervening ground and open the Wasatch vein at depth.

The ground has been opened by a series of tunnels, in two of which most of the work is said to have been done. In December, 1881, one tunnel was in 500 feet; in June of the next year a small vein and some well-stained ground was cut, and in the following August it is reported pockets of ore were found. The next month a vein was struck at a distance of 900 feet from the mouth of the tunnel, trending about parallel to the great McHenry fracture zone. In August, 1888, the lower tunnel was reported to be in 2,250 feet and to have cut, at a distance of 1,700 feet in, a good vein, which on being followed yielded 12 tons of good ore. It appears that during the next two or three years desultory work was done, part of it by lessees, and some fair-looking ground was opened, but with no significant result.

The surface shows that the property lies in the main quartzite area of Bald Mountain and embraces part of the main transecting mass of diorite porphyry. This composite country rock is traversed by fractures, the principal ore bodies trending east and west. The exploration appears to have been directed toward the main contact between the porphyry and quartzite and toward these fissures. It seems most likely that some mineralization took place in connection with intrusion and that postintrusive movement fractured these mineral seams.

LUCY TUNNELS.

The Lucy tunnels are situated at the head of Wasatch Gulch near the wagon road. Development has been carried on by means of three tunnels, two of which were caved in and inaccessible at the time of visit. The third, which opens directly on the road, is shaped like a sickle with the point at the portal. The blade starts toward the northwest, but bends to the south and southeast to meet the handle, which extends due west. In all it contains about 400 feet of workings, including a short crosscut toward the south at 200 feet from the portal. The other tunnels are reported to have over 600 feet each of workings. All the tunnels lie near the contact between the great Weber quartzite body of Bald Mountain and a large intrusion of diorite porphyry. This contact is very irregular so that the tunnel visited penetrates both rocks alternately, but in places the tunnel follows either the contact or the east-west fissures. Fissuring appears to be later than the intrusions and in many places coincides with the contact. The other two tunnels are said to cross the contact and cut some fissures. No ore or mineralization was seen save slight iron stains and heavy impregnations of pyrite in the porphyry.

McHENRY CANYON.

GEOLOGIC FEATURES.

The rocks of McHenry Canyon and its lateral gulches are restricted to the Weber quartzite, the Woodside shale, and the Thaynes formation intruded by irregular bodies of diorite porphyry. The general easterly dip of the beds of the eastern slope prevails in this locality and approaches 40°. In places it is interrupted by low rolls and local variations, as for example the northerly inclinations of the quartzite south of the Hawkeye-McHenry mine and at points in Pocatello Gulch. Though the dip is thus on the whole monoclinal, the beds do not occupy their original relative positions, owing to faulting and fracturing. There are small fissures trending generally northeast and southwest and extensive dislocations in the main zones of disturbance, such as those along McHenry Canyon, where the Weber quartzite is brought down in strike with the Woodside shale by the Frog Valley fault and into juxtaposition with the Thaynes formation by the McHenry fault. The lower course of the canyon leaves the fault line and enters an apron of wash, which conceals the formations to the boundary of the area mapped.

Mineralization in this locality is rather strong and consists in places of slight impregnations of the country rock but most generally occupies fracture zones and fissures. These deposits have been developed, although few are of commercial value. The McHenry lode is a typical fissure deposit and the one most extensively opened.

HAWKEYE-McHENRY MINE.

SITUATION AND HISTORY.

The property comprising the old McHenry mine and the Hawkeye mine is situated in McHenry Canyon and extends from the old Lowell ground, about 1,300 feet east of the divide at the head of the canyon, eastward along the bottom and north side of the canyon for about 7,000 feet.

The record of these historic mines is a story of the exploration of a great fracture zone encouraged by the occasional discovery of small bodies of rich ore and persisting in the face of an excessive flow of water. Ore was found on the old McHenry property in 1870, and this discovery is held by some of the pioneers to have been the first in this district. Its strike under a prominent cropping of rich ore turned the activities of the district toward McHenry Canyon in the earliest days. It was stated that the lowest assay of ore found in a 90-foot tunnel was $22 to the ton, and that 65 assays averaged $200. In view of this fact and of the exceptionally strong surface features, accounts of the rush to locate and eagerness in opening adjacent ground, as the Hawkeye and Lowell, are readily understood. Despite most energetic work and an expenditure of $300,000 during the years immediately succeeding its discovery, the McHenry in 1875 had not been put on a paying basis. Work continued for three years more, the ore found being treated in the mill on the property, and then, in 1878, a body of rich zinciferous lead-copper ore was encountered which was reported to run $60 to the ton. In 1882 the property passed into the hands of a German company and subsequently was idle for a number of years.

The Hawkeye during the early eighties was sinking its shaft, reaching the 300-foot level in 1881, and continued operations against a tremendous outflow of water until, in 1884, part of its works were destroyed by a snowslide. A period of idleness then ensued simultaneous with that in the McHenry.

In 1885 lessees worked a portion of the McHenry ground, but were finally driven out by bad air. In 1890 the old McHenry tunnel was in 2,000 feet and was cleaned out for 750 feet, and some crosscutting had been done. A newly found vein averaging 1 foot in width was yielding bunches of high-grade ore, reported to have averaged 204 ounces of silver to the ton and 77 per cent of lead and to have given some antimony. The property was still owned by foreign capitalists.

Aside from a little work done in the McHenry mine in 1892, the properties in this area remained idle until the middle nineties. All had ore but could not work it, owing to the pres-

ence of water. The Hawkeye on cutting ore in its shaft at a depth of 400 feet struck water, which drove every man out of the mine. Finally, in 1896, the Ontario drain tunnel having been connected through since 1894, the ground of these properties in McHenry Gulch was drained and work was permitted.

In 1901 the McHenry and Hawkeye properties were taken over by a new company known as the Hawkeye-McHenry. Plans were made to work this ground through the Hawkeye shaft after sinking it deeper, and new machinery and all necessary surface improvements were installed.

DEVELOPMENT.

The McHenry ground has been opened by the tunnel that extends along the fracture zone for about 2,000 feet and by a number of shorter tunnels. The Hawkeye ground lying immediately east has been explored through the Hawkeye shaft and its connections. This shaft is down 400 feet, having levels at 200 feet, from which drifting has been done on the vein 300 feet each way, at 300 feet, with a drift running east 250 feet and west over 1,100 feet, and at 400 feet, with drifts either way, but mainly west. The long Hawkeye tunnel extends along the fracture 500 feet westward in Hawkeye ground and thence over 800 feet westward in McHenry ground.

ECONOMIC GEOLOGY.

The geologic structure in the upper part of McHenry Canyon is so irregular that a sketch of the geology of any property, especially the largest—the Hawkeye-McHenry—necessarily covers also contiguous ground.

The bottom of the upper canyon is occupied by Weber quartzite, the northeastern portion of the main Bald Mountain mass. This quartzite is isolated, however, by being cut off on the south by the northwest lobe of the main diorite porphyry mass and terminated on the north by a great east-west break—the McHenry fault. The north side of the canyon is occupied by the Thaynes formation, which has been relatively dropped against the Weber quartzite along the McHenry fault. This would indicate the equivalent of a vertical displacement of at least 1,000 feet, and of a lateral displacement of the south side toward the east of at least 15,000 feet. The general strike of the McHenry fault is east-west or a little northeast and the dip 45°–60° NW. Furthermore, the limestone in the hanging wall, which is also cut by an intrusive mass near the head of the canyon, terminates on the west along the great overthrust known as the Frog Valley fault. This trends in a general north-south direction and dips about 45° W.

Centering at the headward portion of McHenry Canyon two profound faults and great intrusive masses in both the Weber quartzite and the limestone formation afford favorable geologic conditions for ore deposition.

The McHenry fault, one of the dominant structural features of the district, has been the goal of the exploration in this ground. It is a broad fracture zone between quartzite and porphyry on the south and limestone with its included porphyry masses on the north, and has been traced on the surface for more than a mile. Along this outcrop its general course is N. 88° E., and its dip is 40°–60° NW. At the prominent point, about 1,000 feet east of the Hawkeye shaft house, the zone is seen to lie between a hanging wall of metamorphic limestone and a footwall of Weber quartzite and to be marked by a wide mass of intensely crushed quartzite lying over sheeted, less broken quartzite and under sheeted limestone. This intense deformation has almost entirely obliterated other structural planes in the sedimentary formations in this locality.

Underground the Lowell, McHenry, and Hawkeye workings demonstrate that this great fracture zone exhibits similar characteristics at depths of 100, 200, 300, and 400 feet. In the long Hawkeye tunnel, which was accessible for only 300 feet, a zone of strong fracturing is followed S. 50°–60° W. over a footwall of intensely crushed quartzite and under brown and black manganese apparently replacing limestone. It is said to lie for nearly its entire length of 1,500 to 2,000 feet in this great breccia zone.

On the 300-foot level, where the geologic features were best seen, the walls of the breccia zone in the ground east of the shaft are quartzite and porphyry, but west of the shaft, where

seen, unlike those observed at the surface, they were gray limestone or white marble, with some porphyry in the footwall and for the entire length of the west drift crushed quartzite in the hanging wall. The thickness or width of the crushed zone is shown at a point about 700 feet west of the shaft to be at least 170 feet. Here a hanging wall fracture shows the trend to be N. 85° W., the dip 42° N., and the pitch of slickensides 45° SW. Within the general east-west zone several northeast fissures and at least one northwest fissure were noted which were cut by the main east-west wall.

Rich ore outcropped at the base of a prominent quartzite ledge on the McHenry claim. This prominent wall is probably a part of the footwall of the main zone and led to its discovery. The extensive exploration of this zone has resulted in opening a number of rich seams or bunches and small ore bodies, but, so far as known, none of considerable size. Mr. Ellsworth Daggett, who made an examination of the property in its early days, states that in the long tunnel ore was found occurring in spots in the breccia, and at one point, about 1,500 or 1,800 feet from the portal, a fairly good ore shoot was opened.

In the ground entered by the writer on the 300-foot level ore was observed at several places. Thus in following the main fault about 1,100 feet west of the shaft, a fissure was encountered, which, striking N. 55° E., into the main hanging-wall quartzite, and dipping 70° NW., carried 3 to 8 inches of ore and apparently fed a fair bed of ore. Also throughout this great breccia zone metal occurs in the form of thin seams in the cracks in the breccia. Again, in the eastern part of the mine, immediately under the supposed hanging wall, ore occurs in bands in a white quartz gangue. Similar banded ore with quartz was noted southeast of the shaft in the footwall. In brief, the principal occurrences of ore noted were veins in a northeast fissure, a bed adjoining that fissure in seams, in cracks, in the breccia, and in bands intercalated with quartz in the main breccia and its footwall.

The vein was composed of small areas of cleavable galena embedded in sphalerite and associated with quartz. The seams in the breccia were composed of black pulverized cupriferous pyrite, and the banded ore in the fracture and in the footwall were made up chiefly of pyrite and quartz with a little galena.

LOWELL SHAFT.

The Lowell property lies at the head of McHenry Canyon and immediately adjoins the McHenry mine on the west. It was located in the early days upon the great McHenry fissure, and its history is similar to that of its larger neighbor. Invited by the strength of the fissure and the richness of bunches of ore that it inclosed, the search for metals, pursued in spite of great difficulty from water, has consumed much work and money with no fairly compensating return. In 1881 the Lowell shaft was down 240 feet, and some drifting had been done on the 100-foot level on the fracture zone, which was 60 to 100 feet wide, of great strength, and contained bunches of rich ore. In the consolidation of the McHenry and Hawkeye mines the Lowell did not join, and little activity has been shown on the property in recent years.

LADY OF THE LAKE SHAFT.

The Lady of the Lake shaft is situated at the head of McHenry Canyon on the divide overlooking Lake Flat, just beside the main road. It is an old working, now abandoned, which is understood to have been located in this intervening vantage point during the height of interest in catching the eastern continuation of the Ontario lode and the western extension of the McHenry fracture. The shaft is believed to be several hundred feet deep. It was started in porphyry, which would probably continue for a considerable distance. So far as known ore was not found.

AVANDLE MAY PROPERTY.

The property of the Avandle May Co. is situated near the head of McHenry Canyon on the Valeo road, above the Jones shaft. The workings were inaccessible, but consist of a small shaft and some tunnels, which appear to be in diorite porphyry. Northeast fissures traverse the porphyry, but are little if at all mineralized. No ore was observed.

EXCELLENT TUNNEL.

The Excellent tunnel is situated on the south side of McHenry Canyon between the Hawkeye-McHenry and Liberty mines. It is in an area of Weber quartzite, which is truncated on the north by the McHenry fault and severed on the south by an extensive east-west intrusion of diorite porphyry. The beds dip generally northeast at a low angle, but in places approach due north. The tunnel enters on quartzite and extends to the contact with the porphyry, which forms the face of the tunnel. No ore was seen.

LIBERTY TUNNEL.

The Liberty tunnel is situated near the bottom of McHenry Canyon on the nose of the spur just northwest of Wasatch Gulch. It is a straight tunnel, which at the time of visit was over 700 feet long and extends S. 56° W., nearly parallel with the ridge. A small bunk house and a blacksmith shop stand at the portal. The surface in the vicinity is craggy, showing rough ledges of Weber quartzite, which are invaded near the Wasatch mine by masses and dikes of diorite porphyry. In the tunnel the rock is almost wholly quartzite, which dips, as on the surface, somewhat steeply northeastward and is undisturbed except by fissures and slight intrusions. The fissures lie uniformly in the northwest quadrant and are commonly accompanied by a few inches or a foot of breccia and gouge, but one or two midway of the tunnel display zones of crushed rock 3 to 4 feet wide. The intrusions consist of diorite porphyry in the form of narrow dikes and sills, the largest of which, 200 feet from the portal, is 8 feet wide and irregular. A smaller dike and a 6-inch sill occur near the face. The dikes appear to be older than the fissures, which cut and offset them. The only mineralization of the rock observed consists of brownish stains of iron oxides on the fissures and impregnations of iron pyrites in the porphyry. It is reliably stated that persons holding large interests in the Wasatch mine control the Liberty and that the tunnel is designed to intersect the Wasatch vein at depth and serve as a deep work and drain tunnel for the combined properties.

INGERSOL TUNNEL.

The Ingersol tunnel is situated in McHenry Canyon one-third of a mile above the mouth of Pocatello Gulch. It penetrates the southern wall of the canyon for 300 feet in a direction nearly due south. The McHenry fault traverses the opposite slope and brings the Thaynes formation on the north against the Weber quartzite on the south. Hence the outcrops near the tunnel are chiefly quartzites and limestones, but at this particular point a small dike of diorite porphyry invades the quartzite and the tunnel enters and continues for its full length in the porphyry. Slight northeast fissures cross the porphyry, but mineralization is limited to iron stains and to pyritization of the country rock. No ore has been found.

HARWOOD TUNNELS.

The Harwood tunnels are situated in McHenry Canyon near the mouth of Pocatello Gulch. The property is developed by half a dozen short tunnels, four of which at the mouth of Pocatello Gulch are abandoned and caved in. From the dumps they appear to have been driven largely in decomposed diorite porphyry not far from the contact with limestone. Work is now being carried on at the lower tunnels. The one entering the south wall of the canyon a few hundred feet east of the bench mark of the United States Geological Survey is an irregular tunnel extending southward for 375 feet, with a 50-foot drift southwest from its middle point. All the workings are in diorite porphyry, the tunnel being driven, it is said, for the contact with quartzite. The rocks are cut by small northeast and northwest fissures, the former of which are commonly the later. The mineralization is limited to quartz veins along the fissures and to pyrite, which both impregnates the porphyry and occurs on fracture planes and fissure zones. In the latter it is present in loose grains as if crushed and broken by movements since deposition.

The other tunnel examined is located a few hundred feet farther down the canyon than the one just described and enters the north slope. It comprises nearly 200 feet of workings,

consisting of a short tunnel with an arm at right angles. It penetrates largely Weber quartzite with thin beds of soft decomposed limestone, the whole dipping about 45° E. Very slender dikes traverse the main tunnel and all the rocks are greatly broken. The chief zone of brecciation occurs at the forks and trends northeast, but, like the others, is barren. Pyrite, however, is evident in the dikes. No ore was seen.

McCUNE HOLLOW.

GEOLOGIC FEATURES.

The sedimentary series is sparsely represented in McCune Hollow. The eastern margin of the Thaynes formation borders the head of the hollow, and the Weber quartzite flanks the south side opposite the McCune tunnel. These beds retain the general easterly dip of this region, but not without many crumplings, especially in the limestone. Thus locally the beds may be inclined 40°–70° W., but taken as a whole the folded strata slope to the east at angles of 30° to 40°. These beds are of small extent because the larger part of this valley is occupied by igneous rocks. Intrusives of diorite porphyry occur as irregular dikes cutting the sediments and as larger masses surrounding portions of limestone or quartzite. Against these sediments and probably also against the diorite porphyry rests the margin of the andesite extrusive, which, though largely hidden by a thick alluvial fan, no doubt extends eastward several miles beyond the boundary of the mapped district. The deformation in McCune Hollow consists mainly of folding as noted above, but there has also been some fracturing and fissuring. The fissures lie chiefly in igneous rock and on the weathered surface are indistinct. According to the best evidence, however, they trend generally northeast and are very slightly mineralized. Owing to the same vagueness of field indications, it is not possible to say with certainty that the McHenry fault follows the quartzite and diorite porphyry contact into McCune Hollow, but from the crushed, decomposed, silicified character of the porphyry along the contact this seems to be probable. Mineralization is very slight, and there are no deposits known that have been profitably opened.

McCUNE TUNNEL.

The McCune tunnel is situated in the upper part of McCune Hollow at the crossing of the Heber road. At the outset this property consisted of 12 claims, which extended toward the southwest and on which the main tunnel was an active prospect as early as 1884. Development continued steadily and early in 1887 the tunnel, which ran west of south, was 700 feet long. Water was becoming plentiful, but no ore was found until the following year when a small vein was cut. Three samples from this vein are said to have given assays of 70 ounces of silver and 50 per cent of lead; 180 ounces of silver and 50 per cent of lead; 202 ounces of silver, 60 per cent of lead, and $4.50 in gold. Operations were continued and the tunnel reached 2,000 feet in 1890. After that date progress appears to have been less steady and now the tunnel is flooded and abandoned.

The rocks in the vicinity are more or less obscured by gravels. The Weber quartzite, dipping generally to the east, outcrops on the ridge at the south, but it is severed from the Thaynes formation farther west by an irregular intrusion of diorite porphyry. The tunnel is not wholly accessible, but the portal shows that the gravels cover decomposed andesite. To judge from the waste on the dump, quartzite and limestone, probably from the Weber quartzite, were next encountered and the latest rock removed seems to have been diorite porphyry. The waste shows considerable mineralization, but it is confined to varieties of iron compounds, such as pyrite, iron oxides, and botryoidal siderite. There was no opportunity to examine the occurrence of silver-lead ore reported.

SILVER COIN TUNNEL.

The Silver Coin prospect is situated on the south slope of McCune Hollow 125 feet above the south forks of the Heber road. The workings consist of one tunnel, which extends into the hillside 160 feet in a southwesterly direction. The rocks at the portal are thin-bedded

limestones of a siliceous and metamorphosed character. Underground limestones also occur, but they are soft and decomposed and are interbedded with 4-foot layers of quartzite. This calcareous series probably represents lentils in the Weber quartzite or possibly the transitional beds near the base of the Park City formation. The beds dip 35° N. 65° E. and, as shown by the gouge, have undergone considerable movement on bedding planes. Little mineralization is present, and only stains of iron oxides were observed.

DRAIN TUNNEL CREEK.

GEOLOGIC FEATURES.

The rocks of Drain Tunnel Creek valley consist of sediments whose eastern extension is capped by andesite lavas. They comprise the Park City, Woodside, and Thaynes formations, which are very similar in character to those of the type localities, being perhaps somewhat thinner. They maintain the general easterly slope of 35° common in this region, but this is interrupted by deformation so that locally the beds take a very different position. Thus, on the southern pitch of the valley the Thaynes formation especially, and to some degree the red shales, are greatly disturbed by folds whose axes have a common north-south trend. Consequently the beds in places dip steeply to the west. The strata have also suffered from faulting and fracturing along general northeast lines. The faulting has resulted in local bending of the beds, particularly the soft shales, and in apparent thinning of the Woodside shale, and the attendant fracturing has caused minor dislocations and crumplings. On the east the upturned edges of a part of the Thaynes and the succeeding higher formations are blanketed with andesitic lava. Along the edge small hills of the sediments protrude above the andesite surface at isolated points, but farther east the lava continues in unbroken flows until it is in turn overlapped, particularly near the creek, by an alluvial apron of rounded pebbles which extends far beyond the boundary of the area shown on the map.

Mineralization in this locality is slight and is not known to consist of much more than secondary quartz and pyrite along fracture planes.

EAST ST. LOUIS TUNNELS.

The East St. Louis property is situated on the south side of the stage road to Heber, at the head of the second south branch of Drain Tunnel Creek, east of Deer Valley, and immediately adjoins the St. Louis-Ontario ground.

The company was organized about 1901 and undertook exploration in 1902 and 1903. The prevailing rock is of the Thaynes formation. An old upper tunnel enters at about the level of the collar of the St. Louis-Ontario shaft, and it was reported to have been driven more than 200 feet, but at the time of visit it was inaccessible. A lower tunnel, which extends S. 60° W. for about 600 feet, was examined for 550 feet, foul air preventing further progress. This tunnel penetrates limestone of the Thaynes formation, somewhat metamorphosed and dipping N. 60° E. About 135 feet from the portal it cuts a 10-foot porphyry dike trending N. 25°–35° E. and beyond that two northeast fissures. In the walls of some northeast fissures a little pyrite appeared, but no ore was observed.

ST. LOUIS-ONTARIO SHAFT.

The St. Louis-Ontario shaft is situated somewhat over 3 miles east of Park City and 2 miles northeast of the top of Bald Eagle Mountain, on the south side of the stage road to Heber, at the head of the second south branch of Drain Tunnel Creek east of Deer Valley.

The property comprises eight claims and was taken up by St. Louis owners in 1902. At the time of visit a shaft had been sunk to a depth of 250 feet, and a more efficient hoisting engine and surface plant were being installed.

The ground embraces metamorphosed impure limestone of the Thaynes formation. So far as could be learned, no ore had been cut in sinking the shaft.

NORTHERN AREA.

TOPOGRAPHY.

The great canyons that drain the central part of the district converge northward and unite in the main canyon, in which Park City is situated. Deer Valley enters this main canyon from the east and in the northern part of town a short steep canyon descends into it from the west. The east-west spur of the main Wasatch divide, on which the Park City district is located, falls off at this point and the main canyon opens northward upon a low, gently swelling divide. This low and narrow divide separates the head drainage of the Park City Canyon on the east from that of the other canyons of this district lying farther west.

DEER AND FROG VALLEYS

GEOLOGIC FEATURES.

East of Park City and opening into the triangular basin commonly known as Deer Valley Meadow lie Deer and Frog valleys. They are cut mainly in Weber quartzite and limestone of the Park City formation, although shale and porphyry form a large part of the eastern rim of the basin. The general structure of these rocks is that of a crumpled north-south anticline pitching gently to the north, though interrupted locally by reverse dips. The core of the anticline, which occupies the spur between Ontario Canyon and Frog Valley and crosses the hills north of Deer Valley, is composed of Weber quartzite flanked on either side by limestones of the Park City formation. Thus the western slopes of the meadow are uniformly quartzite, whereas the eastern wall is formed by limestone. Formerly this limestone extended over the quartzite arch and connected with the same beds near the Silver King mine, but the limestone was long since eroded from the crest of the arch, and thus an isolated remnant was left on the eastern limb of the anticline. Its craggy edges rise above the meadow on the east, form the twin hills skirting the Heber road, and thence descend eastward beneath the higher Woodside shale. This shale is exposed also near the head of Frog Valley, but its extent is insignificant and it is well cloaked by brush and timber. The dip of both formations is roughly 35° E. In the quartzite, however, the dips vary somewhat, the west slope of Frog Valley displaying eastward and southeastward dips ranging between 15° and 25°.

The general structure thus outlined is broken on the west side of Frog Valley by an intrusion of diorite porphyry along approximately north-south lines. The western boundary of this dike is fairly plain, but its eastward extension is concealed by float and gravels in the valley bottom.

The rocks surrounding the meadow have also suffered somewhat from deformation due to profound faulting. The main fracture zone is the Frog Valley fault, which begins in McHenry Canyon, enters the head of Frog Valley, and either dies out along the eastern edge of the basin or culminates in a fold beyond the boundary of the area mapped. The consequent dislocation, therefore, increases southward, being perhaps very little along the eastern edge of the meadow but at the head of Frog Valley bringing Woodside shale against Weber quartzite, with a crumpled lentil of limestone of the Park City formation between. This main fault seems to have an eastern fork, which appears to branch from the master fault at a point in Frog Valley and to follow the contact between the Woodside shale and limestone of the Park City formation. Companion fissures are numerous in the Weber quartzite, especially at the head and on the east slope of Frog Valley, where they are most apparent as recemented breccia zones. There are also scattered fissures elsewhere in this area in limestone and quartzite alike, which generally seem to fall in a northeast-southwest group.

These various formations are in places hidden by gravel deposits. Small areas of waterworn materials were found on the shoulder near the Constellation mine and at the mouth of Deer Valley, but Deer Valley Meadow exhibits the greatest extent of unconsolidated material. This hides many important geologic features, especially the northward extension of the Frog Valley fault, so that the offset here can not be made out.

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DEER VALLEY CONSOLIDATED TUNNELS.

The Deer Valley Consolidated tunnels are situated at the head of Frog Valley. This property has been under development for many years, having been an active prospect as early as 1886. The workings consist of several tunnels entering the steep face at the head of the valley, but at present all are caved in except one, which is shown on the map near the foot of the west ravine at an elevation of 7,450 feet. Information concerning those that are inaccessible was gained through a member of the company owning the property, who reports that one tunnel in the east ravine extends east of south 800 feet and another in the same ravine runs west about 200 feet. In the west ravine the upper tunnel penetrates southward, it is said, about 150 feet, and the lower tunnel extends in the same direction, being accessible for nearly 800 feet.

These tunnels lie in what is geologically one of the most complicated areas of the district. The Frog Valley fault lies between the east and west ravines of limestone of the Park City formation and is probably continued beneath the débris-covered bottom of Frog Valley and Deer Valley Meadow. The ridge between the two ravines appears to be a fault lentil of limestone of the Park City formation. On the west of the fault lies the Weber quartzite as a huge north-south arch, with its eastern limb abutting against the fault plane. On the east are the Woodside and Thaynes formations, which, though somewhat disturbed by the fault, generally dip eastward. The tunnels entering from the east ravine are reported to be wholly in limestone, the shorter one perhaps striking quartzite near its face, whereas those from the west ravine are largely in quartzite. The upper tunnel is perhaps wholly in quartzite and the lower one largely so. The latter passes through 75 feet of float and then continues for 700 feet in quartzite, which grades into a calcareous series of thin limestones with quartzite layers—probably a calcareous lentil in the Weber quartzite. The structure of these rocks varies somewhat, the direction of the dip near the portal being nearly due east (N. 72° E.), but ranging through north to northwest, reaching N. 27° W. at the cave. Likewise the amount of dip, which is 30° near the portal, decreases to 15° at 700 feet in. The whole series of rocks has suffered much crushing, probably owing to the proximity of the Frog Valley fault; the sheeting is mainly along northeast lines and in places grades into fissures having the same general direction. The fissures range up to a foot in width, and the larger ones have, no doubt, experienced considerable movement, but the direction of it is not evident in homogeneous quartzites. Toward the cave-in, however, the limestone series forms an approximate index to the movement and shows a general upthrow on the southeast side of the fissures. In fact, the presence of the limestone at this level is probably due to such faulting.

Surface croppings of mineralized rock near the tunnels are few. Here and there in the east ravine near its mouth the limestone carries a green gossan of copper-bearing minerals, and the brecciated quartzite on the ridge at the west is browned with iron oxides. If the tunnels of the east ravine penetrate the zone of the Frog Valley fault, as from report they appear to do, the fissure of that zone does not seem to contain ore. In the west ravine the upper prospect is also in an area of crushed quartzite more or less mineralized with iron oxides, and in the main tunnel below it mineralization is limited to common stains of the iron oxides.

FROG VALLEY TUNNELS.

Under the name Frog Valley tunnels may be conveniently grouped those prospects which lie on the west slope of Frog Valley and north of the Deer Valley Consolidated property. Some of them no doubt belong to the old LeCompte claims. They are five or six in number and range from shallow prospect holes to a tunnel 500 feet in length. They lie in an area of Weber quartzite, which is cut by an indefinite dike of diorite porphyry. The dip of the quartzite is generally 10°–25° SE. and may be well measured on the limestone lentils. Most of the workings are wholly in quartzite and others, though beginning in porphyry, end in quartzite. The beds are greatly crushed and broken, generally along northeast lines, and in places develop small vertical fissures. Some iron-stained breccia was noted in quartzite ledges on the surface, but in the accessible tunnels no ore was seen.

CINCINNATI CONSOLIDATED PROPERTY.

The Cincinnati Consolidated property is situated on the eastern side of Deer Valley just beyond the northern margin of the area mapped. The claims of this property were formerly owned by the Sunrise Mining Co., which was reorganized under the present name in July, 1903. The company has opened its ground by a tunnel penetrating the hillside nearly due east for 200 feet and by a short tunnel of 25 feet, which intersects a shaft said to be 117 feet deep. The rocks outcropping in the vicinity are chiefly limestones of the Park City formation, dipping northeastward, but 200 feet below the workings some quartzite ledges outcrop. The relations of these ledges were concealed, and it could not be determined whether they consist of Weber quartzite or quartzite lentils in the Park City formations. The Frog Valley fault if extended northward would run near this point, passing perhaps between the quartzite and limestone outcrops mentioned. The shaft descends through limestone of the Park City formation and quartzite to a drift driven on a north-south fracture zone in marble and quartzite for 30 feet. Halfway down this shaft the rocks cut by it dip 22° N. 45° W. The fissures, which traverse the rocks in a direction east of north, show little mineralization, save iron stains.

SILVER CREEK.

GEOLOGIC FEATURES.

Silver Creek, passing north from the town of Park City, turns eastward through a shallow strike valley and joins Weber River, a branch of Echo River, at Wanship. Park City lies in a central amphitheater of Weber quartzite, bordered on the east, west, and north by the overlying limestone of the Park City formation, dipping outward. At the northwest corner of the pitching arch, where the drainage escapes from the valley, the "bonanza limestone," the Park City formation, coming from the Silver King ground, turns gently northeastward and continues northeast of the town. On this turn to either side of the outlet some deformation and mineralization has taken place. These indications, together with the fact that the country is known from both stratigraphic and paleontologic evidence to embrace the basal limestone beds in which the rich ore bodies of the Silver King mine occurred, have served to stimulate exploration.

CORONA PROPERTY.

The Corona ground is situated upon the northern of the two knobs that stand immediately east and northeast of the north end of Park City. This property, comprising the three claims formerly known as the Donovan group, was acquired by the Corona Mining Co. in the summer of 1903 and incorporated for $500,000. No systematic development of the property had been done up to this time, though an incline of 75 feet was sunk which is reported to have yielded ore giving good returns in gold and silver. Immediately after obtaining the property the Corona Co. started an incline on top of the knob, which at last reports had been sunk 125 feet with a drift from the foot, and subsequently a low tunnel was driven at the creek level, extending at the time of visit for a distance of 200 feet N. 70° E.

The company's ground embraces Weber quartzite on the south dipping about 35° N. and underlying the basal portion (limestone) of the Park City formation on the north. The incline is supposed to be on the dip of the contact between limestone and quartzite. Neither in the incline nor in the drift from it was ore found. The lower tunnel, directed to explore the base of the limestone, cuts basal members and some breccia, but up to the time of visit no ore had been found.

CREOLE MINE.

The Creole mine is situated one-third of a mile west of Park City, 500 feet above the northern part of the town, at the head of a steep gulch.

The property includes a few claims, which were located about 1880 and were worked intermittently during the eighties and nineties. The finding of rich ore early in its history created some excitement. Thus in 1882 a 2-foot vein carrying ore that ran 20 ounces of silver to the

ton and 60 per cent of lead had been developed. Work on a small scale, part of it by lessees, continued to uncover ore, as shipping is reported in 1885, 1886, 1889, 1890, and most actively in 1892, 1894, 1895, and 1896. It has been recorded that the shipments during these first 20 years of its history aggregated in value $50,000.

Late in 1902 the mine passed into the hands of experienced active mining men, who promptly installed a suitable hoist and began sinking the shaft from a depth of 265 feet to 600 feet. Exploration for ore has also been carried on. At the time of visit the underground workings comprised the shaft, a surface tunnel of 250 feet with which was connected a 50-foot level of 500 feet, a level off the shaft at 100 feet 250 feet in length, one at 260 feet 450 feet long, and a short one at 600 feet.

At the surface the formations included are the Weber quartzite on the east and limestone of the Park City formation on the west. The dip of the beds that form the craggy outcrop of the limestone overlooking the shaft is 36° N. 75° W., and that of the quartzite 20° in a direction apparently a little more toward the north. The shaft is situated in a strong northeast fault zone on which the Park City formation is relatively dropped or shifted northeastward against the Weber quartzite. The fault strikes N. 30°–50° E. and dips 59° NW. The mine lies almost entirely in the footwall of this fault and hence in quartzite. The shaft from the collar down, the tunnel, and the 50-foot, 100-foot, and 260-foot levels (except a short northwest drift) are in Weber quartzite. On the 260-foot level the northeast fault is cut, a broad zone of breccia is penetrated, and the down-faulted limestone is probably reached, though an extension of this drift would strengthen the evidence on this critical point. Slickensides in planes in this breccia zone dip 30°–40° NE., a direction which, together with the position of the limestone, indicates that this formation relatively descended northeastward. It is understood that the plan of development of the new company was to sink below the oxidized zone in the fine quartzite footwall, then crosscut the fault zone, and explore the basal members of the Park City formation. At the time of visit insufficient work had been done to show the best depth for this exploration.

All the ore found up to the time of visit was apparently taken from the tunnel and the 50-foot level in or adjacent to fractures in quartzite. In general, the quartzite is broken along northeast and northwest fractures. The ore occurs about 150 feet south of the shaft at the tunnel, 50-foot and 100-foot levels, and thence at a number of points for 500 feet southwest. It lies both in fractures and along more open, perhaps slightly calcareous intercalated beds in irregular pockets. One of the clearest instances of this mode of occurrence noted was along a N. 19° E. fracture zone 30 feet in width and dipping steeply southeast. A number of northwest faults were seen which seemed to be later than the northeast series, also later than the ore, and to truncate the deposits.

The ore first discovered on the property is reported to have been a "carbonate lead and silver ore." The ore noted in the walls of fissures and in pockets and vugs is oxidized lead ore, probably with silver. It is apparently made up of oxides and carbonates and sulphates of lead with corresponding oxidation products of silver.

NIGGER HOLLOW.

The valley known as Nigger Hollow lies a mile west of Park City, heading on the north side of Treasure Hill, and is drained northward through the easternmost branch of East Canyon Creek. The rocks surrounding the hollow belong to three formations—the Park City, Woodside, and Thaynes. These lie one upon another, dipping gently to the northwest. Hence the east side of the hollow is nearly a dip slope of limestone of the Park City formation, but the western limb is made up of the craggy edges of all three formations, the Woodside shale occurring as a red band between the basal limestone of the Park City formation and the crest-making Thaynes formation. In this small area the northwesterly monocline seems little disturbed except by minor fracturing and fissuring in a general northeasterly direction.

The Minola tunnel is situated on the eastern slope of Nigger Hollow at an elevation of nearly 7,150 feet, which brings it near the margin of the district mapped and a little below the abandoned Crescent tramway.

Prior to 1902 this property of 175 acres was opened under lease by means of a tunnel entering the hillside in a southeasterly direction more than 360 feet. After that date the present company began sinking a winze near the face of the tunnel, which at the time of visit had reached a depth of about 500 feet. About 400 feet from the surface, or 240 feet below the tunnel level, drifts are turned northeast and southwest, each extending about 150 feet. There is also a crosscut of 135 feet running southeast.

The outcrops near the mine are of limestones and calcareous sandstones belonging to the Park City formation. The stratigraphic succession is best shown along the tramway cut, but the fossils are most abundant near the tunnel mouth. Trees and brush cover most of the surface near the workings, consequently the rocks may be best studied underground. The tunnel runs for some distance from the portal in calcareous sandstone and the remainder of the horizontal workings penetrate dark limestone overlying blue limestone. The upper part of the winze, however, penetrates a 30-foot bed of quartzite and its foot has, it is said, been in quartzite for 90 feet. The intervening rocks are limestones and the quartzite layers are presumably those that commonly occur in the lower part of the Park City formation. These rocks dip 25°–35° N. 55° W. The workings are remarkably free from strong and extensive fissuring, but some marks of such deformation are present, and the fissure followed by the northeast and southwest drifts is the most important. This fissure has a zone of brecciated rock generally a foot wide, though in places very narrow, and its dip is 70°–80° SW. The attitude of the grooves on the fissure walls indicates horizontal movement, but in the section of rocks exposed in the mine the limestone of the footwall overlies the dark limestone of the hanging wall. Therefore, unless limestones of similar color occur elsewhere in the unexposed section and unless the fissure elsewhere changes its course, which here is on the strike of the beds, the evidences of movement exhibited in the grooves and in the juxtaposition of beds are contradictory. This fissure and its companions which extend roughly northeast and southwest sever and offset the less prominent northwest fissures, but to judge from the amount of gouge, there has been considerable motion along the bedding planes since the northeast fissuring took place.

No commercial ore has been seen and the mineralization was limited to stains of iron oxides along the main fissures, green stains (of copper mineral?) reported on a fissure in the winze, and impregnations of pyrites in the blue limestone. The dark limestones contained no pyrite and it may perhaps be said that the mineralizing agents preferred the purer rock.

WESTERN AREA.

GENERAL GEOLOGY AND TOPOGRAPHY.

The western part of the Park City district forms a geologic unit unlike either the central or the eastern part and is in turn made up of two geologically distinct portions, the northern and the southern. The northern portion is a monocline composed of the Thaynes formation and the Ankareh shale (both Triassic) and the Nugget sandstone (Jurassic or Triassic), dipping from the west side of the Park City anticline toward the northwest. In the southwest quarter the main divide of the Wasatch Range is maintained on the great series of intrusive rocks that have cut entirely across the range from valley to valley. In this locality these rocks comprise the granite at the head of Thaynes Canyon, the great stock of diorite culminating in Clayton Peak, the highest mountain in the region (10,728 feet), and on the east the extensive irregular stock of diorite porphyry.

The northern portion of the western area is divided topographically by a system of northward-flowing streams, which have carved out valleys roughly along the strike of the sediments, into a series of parallel subsequent valleys. The physiography of the region exhibits a number of singular problems, such as the development of the interstream ridge between Bogan and Thaynes gulches and the sudden drop north of Iron Hollow, which do not come within the scope of this paper.

The entire series of strata, from Weber quartzite and Park City formation at Nigger Hollow to the heavy white Nugget sandstone that caps the Ankareh shale above Iron Hollow, are rep-

resented. As a whole, the structure is that of a normal monocline. The regular northwesterly dip is apparently interrupted, however, by strike faulting, which tends to exaggerate the actual thickness of the beds. Blanketing the bottoms of the canyons in this area are comparatively thick but narrow glacial deposits, chiefly in the form of ground moraine.

The principal valleys of this division falling within the district are, from east to west, Thaynes Canyon, with a short gulch entering it from the east; Whitepine Canyon; and an unnamed gulch which unites with Whitepine in Iron Hollow.

The southern portion of the western area includes the part of the main divide of the Wasatch Range extending from Scott Hill to Clayton Peak and the slopes running westward therefrom and forming the eastern head of Big Cottonwood Canyon. It thus embraces the highest points in the district, Scott Peak (10,127 feet) and Clayton Peak (10,728 feet). From this master divide the several short canyons that head just within this area descend to the great flat bottom of the extensive amphitheater at the head of Big Cottonwood Canyon, west of the Park City area.

Geologically this region is made up of the Clayton Peak stock of diorite at the southwest and a smaller tongue of granitic intrusive rock adjoining it on the north, which together break up across the Thaynes formation. The contact between these intrusives and the sediments forms the valley and gap at the head of Thaynes Canyon, and the contact-metamorphosed and more resistant sediments constitute Scott Peak.

THAYNES CANYON.

GEOLOGIC FEATURES.

Thaynes Canyon is the most important valley, both in mining and in topography, in the northwestern part of the Park City district, and it forms the main thoroughfare between this district and the Big and Little Cottonwood region. Heading in a circular amphitheater far up on the main divide of the Wasatch, it descends northeastward as a deep, narrow, steep-sided canyon. The relief at its head from Shadow Lake to the summit of Jupiter Hill is 1,000 feet, and it has practically no tributaries in this area, the short Bryan Gulch uniting with it just below the lake. Its drainage basin is exceptionally narrow. About its head to-day the slopes are, for the most part, stripped of the heavy forest growth existing a few years ago and, except in a few places, show comparatively thin soil and bare craggy ledges. In its lower portion, only here and there does bedrock appear through the mantle of glacial waste.

The canyon has been mined for nearly its entire course in Triassic limestone of the Thaynes formation, which it well exposes and to which it appropriately gives its name. Overlying this extensive exposure of the Thaynes formation, at both the northwest and the southeast heads of the canyon, is the Ankareh shale, and above that the Nugget sandstone. At the southwest head a granitic intrusive breaks across the sediments and extends eastward to the bottom of the amphitheater. The general dip of the beds is 20°–30° NNE., but is interrupted by northeast fissures.

Certain features of the geology of this canyon merit a somewhat more detailed description than is given above. The distribution and boundaries of the formations suggest dislocation. The Thaynes formation, having a thickness of 1,290 feet in the type section on the west and apparently about the same here, with its dip obscured, seems to occupy an abnormal area. This apparently exaggerated thickness is believed to be due to compound faulting roughly parallel to the strike, which has produced a succession of step faults. It will be noted from the map (Pl. II, p. 44) that the succession occurring at the northeast is duplicated roughly at the southwest. The white Nugget sandstone and the underlying Ankareh shale, which outcrop along the crest of Pioneer Ridge, were clearly dropped on the southwest along the great Crescent zone so that the top of the Ankareh abuts against limestone of the Thaynes formation. This zone of strong faults continues northward and is about 1,500 feet wide. On this northern member of the zone crossing from the Comstock mine, near the Crescent mine, and northeastward this upper series ends and the middle red shale and underlying lower members of

the Thaynes formation come in. These beds strike northeast around the north end of Crescent Ridge to the Bogan mine water tank. Thence northward the limestone is the lower part of the Thaynes formation. Just as the main area is thus divided and the thickness of the limestone apparently magnified by two western faults, which relatively lower the southeast sides, so within these main blocks are many sympathetic minor faults that act in a similar way.

This step faulting, although the most extensive and important deformation in this locality, is not the only one. The granite at the head of the canyon breaks raggedly across the sediments and deforms them, and on the north side of the canyon they are cut by a mass of diorite porphyry extending northeast.

About the head of the canyon recent modifications have taken place. Above Shadow Lake the bedrock is polished and grooved. The bottom of the amphitheater is covered with mixed débris of the rocks forming the divide, including granite, diorite, porphyry, and metamorphic limestone, and the soil is heaped in hummocks or kettle moraines. The bottom of the canyon is on an excellent ground moraine and perched on the sides of the canyon are remnants of lateral moraines. Finally, at several points on the steep slopes inclosing the amphitheater the canyon topography, as modified by glaciation, shows still further changes. At the west head of the canyon, above the California and Comstock mines, a subbench and hummocky surface lies below a gap in the divide and these facts have been taken as evidence of a landslip. A similar mass lies just above Shadow Lake, north of Jupiter tunnel.

The ore deposits that have been found in ground opened from Thaynes Canyon lie in limestone of the Thaynes formation, generally near diorite porphyry, and in fractures or on beds adjacent to fractures. The ore is silver-bearing lead ore, with considerable zinc.

SILVER KING CONSOLIDATED PROPERTY.

The Silver King Consolidated property is situated at the head of an unnamed gulch which descends to Thaynes Canyon from the east and lies next west of Nigger Hollow. The ground adjoins the Silver King Coalition ground on the northwest. The nucleus of the property is the old Cumberland claim, which, with two others, formed the Bogan property. Considerable work was done on the Cumberland, and in 1893, 1894, and 1895 ore strikes were reported. In July, 1903, the old company passed into the hands of the new organization under the name Silver King Consolidated. The Bogan shaft, which had then reached a depth of 610 feet, was sunk to 790 feet, in spite of the difficulty of handling a heavy flow of water. New machinery of greater capacity, both for hoisting and pumping, was then installed. It is reported by the company that the shaft was sunk to a depth of 800 feet.

The development work comprises this main shaft, 800 feet in depth, with some drifting on the 600-foot level; the Cumberland incline, extending 175 feet on its dip, with short laterals; a lower tunnel about 100 feet in length; and a number of shallow prospects.

The surface is occupied entirely by limestone of the Thaynes formation. It is clear, however, from exposures in the gap at the head of the gully, in the shaft, and in other workings, that it is only the lowest portion of the limestone, and that through much of this ground the underlying red shale approaches close to the surface. The prevailing dip of the sediments is 20°–40° NW. At the top of the ridge it is 19°–28°, averaging 22° N. 10° E.; at the head of the Cumberland incline it is 20°–30° N. 50° W.; at the lower tunnel it is 25° N. 50° W.; and on the east side of the divide in the rear of the Silver King office and bunk house it is 20°–33° averaging 30° N. 35°–40° W. The dip is considerably disturbed, as shown in the Cumberland incline by fracturing and faulting. The ground lies in the general course of the great Massachusetts fault, and though the line of that fault could not be traced, it is not improbable that the same forces which produced it operated to disturb this ground. The gap at the head of the gully lies on a northwest fault, which may be correlated with the fissuring discovered by the Cumberland incline. The offset on this fault, as marked by the contact between the Thaynes and Woodside formations, is in the same phase as that on the Massachusetts fault but amounts to only about 200 feet, and furthermore it lies considerably southwest from the direct course of the main fault. Yet it is not impossible that the great thickness of shale took up much of the

displacement and deflected the forces so that this gap fault may represent the Massachusetts fault. Some such dislocation and large untraced faults may account for the apparently excessive thickness of red shale cut by the shaft.

The shaft started in the basal 30 feet of limestone of the Thaynes formation, next descended through the red Woodside shale for 800 feet, and then reached the Park City formation. The 600-foot level drift is in red shale. No ore was encountered in this development work, but an excessively heavy flow of water, which it seems the shale holds to an exceptional extent, proved a serious handicap. The Cumberland incline follows a slip plane down at an angle of 36°, or including the lower steeper portions 40°, for about 175 feet in the Thaynes formation, dipping normally northwest. The slip is inclined somewhat more steeply than the bedding, which dips near the head of the incline 20°–30° N. 50° W., along the northeast drift 35° S. 45° E., and at the foot, under a north-south fissure dipping west, 35° W. It is probable that whatever ore has been struck was found in this incline or the several short drifts from it. The lower tunnel cuts red shale, red sandstone, and transition beds to brown clay shale but opens nothing of commercial possibility.

COMSTOCK MINE.

The Comstock ground is situated in Thaynes Canyon a mile northeast from the pass at its head, half a mile north of Shadow Lake, and immediately north of the California mine and west of the Kearns-Keith mine.

This property comprises three claims covering an east-west band mainly on the west side of the canyon. The occurrence of good ore in this ground was demonstrated by surface work doubtless begun at the time when attention was drawn to this region by discoveries of ore on Crescent Ridge. After various endeavors to develop it had been made, with scanty resources, the Comstock Mining Co. was organized and incorporated in London, in 1882, with a capitalization of $1,250,000. Since that date underground development and surface improvements have greatly improved the property. It was especially active in 1890, 1893, 1894, 1895 (when a good ore body was struck), and 1901 (when the shaft was being sunk). Considerable shipments have been made, particularly during periods of spring waters which permitted operating the mill, but the total amount or value is not known.

The plant comprises a modern mill, a hoisting equipment, an office, and a bunk and boarding house. The mill has a capacity of 120 tons a day and is equipped with one wet crusher, three cylindrical screens, an elevator, three jigs, one Huntington and six Wilfley tables, and an arrangement for receiving steam and water from the shaft plant.

The property had been developed at the time of visit by numerous surface prospects on croppings, by a main tunnel driven southwestward at the creek level about 2,000 feet, and by a main shaft 350 feet in depth with a main level at 250 feet and 2,500 to 3,000 feet of workings. The tunnel and the main level 200 feet below it are connected by an inclined raise on ore, from which three short intermediate levels have been run on the vein. From the bottom level three raises have been opened on the footwall of a back vein for 55, 65, and 70 feet. After the visit to the property it was stated that the shaft was sunk to a depth of 450 feet, and drifting westward for the vein at that level was begun.

The ground occupied by this property lies in the main area of limestone of the Thaynes formation. That part which has been explored for ore lies stratigraphically below the Pentacrinus zone or upper limestone of the Thaynes formation and above red shale; thus it is the lower part of the Thaynes formation. This part is composed of sandy limestones, calcareous sandstones, and some normal blue limestone, but as a whole is impure, somewhat arenaceous limestone. The prevailing dip is 22°–40°, with an average of about 30° N. 30°–50° W. This general area of limestone is divided on the surface by a narrow, locally thick strip of waste and glacial material which covers the bottom of the canyon throughout its length in the district. Glacial moraines also blanket parts of the overlooking slopes even to a height of 300 feet above the present valley bottom. So far as could be observed no porphyry is exposed at the surface, though it would be expected, to judge from underground exposures. On the bench north of the

shaft are large rounded bowlders of a granular igneous rock, which appear to be float-borne from the head of the canyon by ice. Fractures are numerous, commonly in east-west or northeast-southwest directions.

The shaft passed through 50 to 75 feet of wash, then red shale, porphyry, limestone, and porphyry, and into limestone. At the face of a crosscut running northwest from the tunnel is red shale dipping 22° N. 49° W. The prevailing country rock is limestone of the Thaynes formation which appears to underlie the shale and to have a similar dip. Traversing these beds in a northeast-southwest direction are porphyry bodies at the northeast and southwest parts on both the tunnel and the 250-foot level. Although these bodies have not yet been proved to be continuous on either level between levels, their general position, strike, and dip indicate that they are parts of the same strong dike. By further development it may be determined whether these parts are continuous, were originally so, and have since been broken by faulting, or were always separate masses in a common zone. The porphyry truncates the bedding obliquely and crushes the adjacent walls 3 to 8 feet, especially the hanging wall. It is the coarse diorite porphyry, and at the southwest on the 250-foot level apparently passes gradually into a highly micaceous facies.

This composite country rock is cut by northeast-southwest fissures, which dip southeast. Several of these fissures are overthrust planes on which the east side is thrust up and over upon the west. At the extreme southwest end of the 50-foot level the main northeast zone appears to be cut off by a northwest fissure. The ground adjacent to the porphyry is highly fractured and crushed and in many places silicified. The nature of the shearing at the west face of a crosscut at the southwest end of the 250-foot level strongly suggests that the intrusive entered this ground from the east and broke its way upward and westward.

These fracture zones in the hanging wall and in the footwall of the dike are the loci of the ore bodies found in this property. In the hanging-wall zone two main shoots, the eastern and the western, have been developed. The eastern shoot is a zone of ore-bearing breccia 2 to 8 feet wide in the general fracture zone having the dike as a footwall. The western shoot appears to be a V-shaped body in the corresponding fracture zone in the hanging wall of the dike. Striking about N. 25° E., a little more easterly than the dike at this point, it approaches the intrusive at the south, being about 40 feet east of it at the north part and 10 feet at the south, where, moreover, it appears to terminate on a northwest fissure. This southward convergence results in a northward pitch of the shoot. In depth the continuation of the shoot, which descends at a different angle from that of the dike, may or may not be truncated or may meet and descend upon the dike, though the dips observed suggest that the fracture zone approaches the dike in depth. The portion of this wedge-shaped shoot explored is made up of thin-bedded and massive metamorphic limestone. Its hanging wall is a clean, strong fracture zone standing nearly vertical. Within these shoots the metallic mineral occurs in two ways, as seams of cupriferous pyrite and chalcopyrite one-fifth of an inch to 2 inches thick, and as beds of the same making out from fissures along certain beds of the limestone.

In the footwall west of the dike some mineralization occurred both at the north and south, but no commercially valuable bodies were discovered. At the north where opened on the tunnel level and the 250-foot level only a few bunches of ore were found. At the southwest on the footwall side pyrite occurs disseminated and in 2 to 4 inch seams. One such seam of cupriferous pyrite lay along the base of the porphyry between it and the underlying limestone. The contents of this footwall material, however, were too low in copper to permit it to be mined for ore.

The ore is mined for lead and silver. On the tunnel level these metals were carried mainly in cerusite and anglesite and copper in malachite. On the 250-foot level the ore was made up chiefly of galena and pyrite in both massive and crystalline forms, associated with a large amount of sphalerite and some calcite. Some of the ore is of excellent grade for smelting, some requires the reduction of zinc to become commercially valuable, and much of it requires concentration of the scattered values.

CALIFORNIA MINE.

The California ground is situated on the west side and near the head of Thaynes Canyon, immediately south and west of the Comstock mine.

This property comprises about eight claims, which have been prospected from time to time. Its history seems to be made up of a number of movements from one part of the property to another, each probably following some new favorable development. Thus in the swinging of the pendulum Thaynes Canyon was the point of prospectors' interest in 1881, 1883, 1889, 1893, and 1900. In 1883, it is said, the camp fires in Thaynes Canyon gave the place the appearance of an army encampment. Early in 1893 the California mine was reported to have suspended operations, owing to an excessive flow of water, and to have resumed work in March. In March, 1895, lead ore that carried considerable zinc had been found, and the lower tunnel was started. Enough low-grade ore appears to have been uncovered in the next five years to lead, in June, 1900, to the purchase and remodeling of the old Apex mill, which was running by August of that year. A good body of ore was opened the succeeding year. Subsequently a dispute arose between certain officers of the company and certain interests in it, also, it was understood, between the Comstock and California companies as to the ownership of certain ore under the apex law. During the present examination of the district the property was idle.

The plant includes the small mill obtained from the Apex property, remodeled and with Wilfley tables added, a small shop and an office.

The ground has been explored by two tunnels, the lower or main tunnel near the creek level and the shop tunnel 100 feet above, by an intermediate level between the two, and by a shaft from the hillside to a depth of 185 feet, or 20 feet below the lower tunnel. The intermediate level is connected with the tunnel level by a chute and with the shop level by a 20° inclined stope. Both tunnels extend northwestward, the lower about 500 feet and the upper about 100 feet to the main workings, which comprise an extensive stope, a northeast drift of about 600 feet on the intermediate level, and two roughly parallel northeast drifts of 600 and 400 feet on the lower level.

The lower part of the slope on the California ground is largely covered with glacial material and the upper part with float, so that bedrock was not observed in the vicinity of any of the workings. On the west limestone of the Thaynes formation outcrops. Dumps at prospect holes indicate that the underlying bedrock is metamorphic limestone of the Thaynes formation with dikes of biotitic porphyry.

Underground the country rock is metamorphic limestone and calcareous sandstone, with a transecting dike of porphyry. The prevailing dip of the sediments is 10°–20° N. 5°–35° W. The width of the dike is about 42 feet; the strike of the east wall where it is cut by the shop tunnel is N. 55° E. and by the lower tunnel N. 40° E., and the dip at these points is toward the southeast at angles of 32° and 60°, respectively.

The country rock is traversed by a great number of fissures, most of which trend N. 45°–60° E. and dip steeply toward the east or stand vertical. The main zone of fracturing is in the footwall of the dike and extends northeastward parallel to it, being over 100 feet wide on the shop and intermediate levels and nearly as wide on the lower level. The dip of a branch, which is followed southwest on the lower level toward the shaft, is 75° SE. and the dip of the foot of the main zone at the northernmost point where it is cut on the bottom level is 85° SW. Beyond this master zone toward the northwest are several strong northeast fissures dipping southeast, and about 100 feet from it lies one that has been followed southwestward for about 400 feet, dipping 60°–75° SE.

No concrete indication of the direction of movement on the master zone was found, though small traces showed movement upward on the west at some points and downward at others. On the whole the strong series of northeast faults dipping eastward against the bedding suggests a force from the east tending to thrust the eastern member up and over the western and relatively dropping the western. Considerable movement also occurred along bedding planes.

Mineralization seems to have taken place either along or adjacent to northeast fissures in a series of thin-bedded shaly limestones. Both true lode deposits and characteristic bedded

replacement deposits occur. The principal mass of ore is a lens in the footwall of the main fracture zone, lying along the bedding, dipping northward, and divided into a series of minor lenses adjacent to northeast fissures. These fissures appear not only to have afforded the pathways for the ore-bearing solutions, so that the lens is elongated along them, but they also served for post-mineral fault planes, on which the ore beds appear to have been relatively elevated in progression from east to west, thus stepping the ore. In the western part of the ground a somewhat different type of occurrence was noted, namely, a shoot in the fissure and replacing a certain adjacent inclosing bed, pitching within the fracture zone with the dip of that bed.

The ore is a silver-bearing lead ore, of milling grade with much associated zinc and a generally calcareous gangue. Galena, the common source of the lead, is in large part embedded in a band of brown sphalerite. Cupriferous pyrite, both granular and crystalline, occurs in the same manner, also in veinlets on joints and slip planes and disseminated through metamorphic limestone. Some of the silver may be traced to jamesonite, which occurs sparingly in the form of minute bands and tufts of hairlike crystals in metamorphosed limestone within bands or lamellæ of silica. The high proportion of sphalerite is noteworthy.

KEYSTONE PROPERTY.

The Keystone ground is situated in upper Thaynes Canyon on the southeast side, adjoining the Kearns-Keith ground on the southwest and the Balmount on the northwest.

The property comprises about a dozen claims lying in a northeast-southwest zone along the basal slopes of the canyon. It was prospected in the early days, but no systematic development was ever carried out. About 1903 it was taken up by a strong company understood to be backed by some of the largest mining interests in the district and regular development was started. The underground workings comprise several old prospects, an old upper tunnel, an old long middle tunnel, a lower tunnel extending southeast 700 feet, with 700 feet of lateral drifting, and a shaft at least 240 feet in depth.

The tract lies in the path of some of the greatest deformation in the entire camp and consequently its geology is extremely complicated. Furthermore, the elucidation of its complex relations is seriously hampered by local waste deposits and by the heavy growth of vegetation favored by the moisture on this protected slope. In general the Thaynes and overlying formations are broken and faulted by east-northeast fissures and invaded by dikes of diorite porphyry and peridotite. Broadly considered, the effect of this faulting has been to sever geologically the ground on the north from this tract by a profound east-west fault on which the southern member has been dropped many hundred feet.

Northeast of the shaft, at the crest of the divide, a thin bed of the coarse white Nugget sandstone that overlies the Ankareh shale outcrops on the south side of the main Crescent fault, by which it is dropped against limestone of the Thaynes formation. The sandstone extends some distance down the west slope of the ridge and some red shale is exposed on the surface and in tunnels. The bedrock is so masked and the faulting is so complicated that the complete formations could not be accounted for. The prevailing dip is 30°–40° NW. The trend of the Crescent zone of faulting and of the zone that crosses the divide several hundred feet farther south is east-west or about N. 70°–80° E.

Underground the main lower tunnel cuts limestone of the Thaynes formation dipping in general 35° NW. This is traversed by N. 40°–60° E. fissures, which usually dip 40°–70° SE. Along the strongest fissure zone are 5 feet of gouge and decomposed limestone. The limestone adjacent to an irregular fissure zone near by is heavily impregnated with pyrite. So far as learned, no ore had been cut in the shaft, which was being sunk at the time of visit. The upper tunnel, extending about 85 feet southeastward, was run in gray limestone and black metamorphic slaty limestone without finding ore. The middle tunnel was caved in and inaccessible, but its dump showed malachite, azurite, and galena in silicified limestone. A dump at a tunnel just above an upper trail showed red shale, altered sandy limestone, and decomposed porphyry. So far as was ascertained no commercial bodies of ore had been cut up to the date of visit.

JUPITER MINE.

The Jupiter property embraces the ground about the extreme southern head of Thaynes Canyon, from the main divide down nearly to the valley bottom. It comprises about a dozen claims, which were located early in the history of the camp and have been worked by a number of different persons. After pioneer prospecting the property was brought to a shipping basis in the early eighties. By the close of 1886 a good vein had been traced continuously down for 200 feet. During the succeeding year 50,000 pounds of high-grade ore was shipped and a deep lower tunnel was started, which was run during the next few years. In 1888 a good shoot of rich carbonate ore was opened, and the next year lessees were working this ground. In 1890 the Jupiter property was incorporated at Council Bluffs with a capitalization of $3,000,000. In 1894 some ore was taken out, and in 1900 the main vein had been opened 300 feet on its dip and yielded excellent ore. It is reliably reported that about five years later, after a period of inactivity, the main tunnel was extended several hundred feet until it crossed the main vein and was then turned and brought back across it toward the south, where a good body of rich lead-silver ore was found. Shipments from this shoot were being made regularly in 1906.

The ground has been opened by an incline sunk from the gap in the main divide at the head of the gully and by a series of tunnels, which enter the canyon wall at different elevations, ranging from one near the top to one near the base of the slope. One incline in the gap appeared to be about 150 feet deep and one is reported to have been sunk 300 feet on a vein. The lower or main recent work tunnel is over 800 feet in length. The tunnels in general extend southeastward and the incline dips steeply in the same direction.

The country rock comprises very highly metamorphosed limestones, shales, and sandstone, which in some places are now marble, slates, and quartzites, respectively. These sediments are so altered as to hide their normal lithologic character and to render identification by fossil remains impracticable. The intense deformation in this area prevents precise stratigraphic correlation with known beds, as a rule. It is probable, however, that the greater part of these metamorphic sediments are members of the Thaynes formation, and some may be younger. East of the gap, along the divide toward Jupiter Hill, is metamorphic shale and a small mass of monzonitic intrusive rock so altered and filled with biotite phenocrysts as roughly to resemble schist. West of the gap are marble and metamorphic shale and limestone, and the tunnels cut metamorphic limestone, black slaty beds, some quartzitic sandstone, and siliceous limestone. In the gap are green shale, gray argillite, quartzite, metamorphic limestone, and ferruginous breccia.

The gap has been eroded along a zone of weakness formed by fracturing and brecciation. The fissures in this general northeast zone range from N. 30° E. to N. 70° E. in trend. The most brecciated and iron-stained zone trends in the gap N. 45° E., and in a tunnel running north below the gap is a strong fissure trending N. 32° E. The prevailing dip is 45°–85° SE., the higher angles being most common. The distribution and truncation of the quartzite, shale, and limestone in the gap indicate considerable complicated faulting.

This zone or particular members of it form the locus of the ore and have been the object of search through the inclines and tunnels. It is understood, though it could not be personally determined owing to the condition of the workings, that the ore occurred as a lode on a northeast fracture zone dipping steeply southeast, which was followed down by inclines for over 300 feet and was cut by the bottom tunnel and certain others.

The ore that was last shipped from the property, that from the lower tunnel, like the ore from the incline at the crest of the divide, is stated to have been a rich silver-bearing lead ore. That from the higher parts of the lode was said to have been a carbonate and that from the lower tunnel a sulphide. From the dump at the mouth of the lower tunnel specimens were taken, which show massive and crystalline pyrite, a little recent azurite and malachite, and probably gray copper, in a gangue of calcite and probably dolomite, and much specularite with garnet and quartz.

SUMMIT EXTENSION PROPERTY.

The property of the Summit Extension Co. is situated at the head of Thaynes Canyon, in Brighton Gap. Development of the property is going on by means of a shaft reported to be 100 feet deep and to have two drifts. An incline has also been sunk a few hundred feet west of the shaft and is said to be 200 feet long, but was partly inaccessible at the time of visit. The rocks in the vicinity are diorite porphyry on the south and limestone of the Thaynes formation on the north, the contact of the two occurring in the gap just north of the shaft. The workings seem to be wholly in diorite porphyry, thougn the limestone contact might be penetrated a short distance farther north. The shaft being inaccessible, mineralization is judged from the dump, which displayed considerable gypsum as well as pyrite. The gypsum probably occurs as veins; the pyrite appears to impregnate the porphyry. The same pyritized porphyry occurs in the incline, but in addition it is reported that at 90 feet from the portal a 4-foot vein was intersected. This is said to assay gold to the value of $5 a ton.

THAYNES CANYON CONSOLIDATED INCLINE.

The Thaynes Canyon Consolidated property is situated in Thaynes Canyon 2 miles below the Comstock mine. The main development has taken place through an incline. This was started in the glacial material that covers the floor of the canyon, but both walls are largely limestone of the Thaynes formation, which dips gently to the northwest. The incline, which was partly inaccessible at the time of visit, seems to lie wholly in this formation and to cut the middle red shale, which is about 60 feet thick.

D. & M. TUNNELS.

The D. & M. property is situated in Thaynes Canyon adjacent to the Comstock ground on the north. It comprises about five claims, which lie along the bottom and west side of the canyon. The ground has been developed through three tunnels driven northwestward—two upper tunnels and a main work tunnel near the creek or road level. The main tunnel extends north-northwest 400 to 500 feet and drifts are carried out laterally along fissures. The two inner drifts, over 340 feet from the mouth of the tunnel, are the principal ones. They run northeast and southwest of the tunnel and aggregate more than 175 feet in length.

On the surface of this property limestone of the Thaynes formation is exposed. Underground the lower tunnel cuts red shale near its mouth and thence inward to the face shaly, siliceous, and gray limestone dipping 20° NW. This limestone is traversed by northeast-southwest fissures and sheeting. The strongest are the two near the face, trending N. 58° and 60° E., and dipping 77° and 75° SE. The outer of these two is a 6-inch zone of sheeting; the inner and main one is a strong fracture zone, in places 5 feet wide and at some points mineralized. From a raise on this zone, reported to extend to an upper level, limonitic oxidized material was taken. Some ore is said to have been shipped from the property.

SILVER BELL TUNNELS.

The Silver Bell tunnels lie north and west of the D. & M. ground, mainly along the crest of the divide overlooking Thaynes Canyon from the west. The property includes about half a dozen claims. They have been opened through two upper tunnels and an extension of the main California tunnel northwest for about 500 feet.

The country rock on this property is the upper part of the Thaynes formation, as shown by the fossils found at the mouth of the upper tunnel by the road. It is traversed by east-northeast fissures and a persistent dike of diorite porphyry.

The upper tunnels revealed a mineralized northeast fissure dipping southeast. None of these levels is connected with any other. The lower tunnel, or extension of the California work level, cuts northeast fissures dipping southeast, and from one broad zone of fracturing some good ore was taken. Up to the time of visit no shipments had been made from this property, although about 10 tons of excellent ore is reported to have been mined from the recently opened lode, sinking on which was in progress.

OLDHAM GROUP.

The Oldham ground is situated on the east side of Thaynes Canyon, about 1⅓ miles northeast of the Comstock shaft. The Thaynes, which forms the prevailing formation in this locality, is covered by a considerable area of glacial material along the top of the ridge on the west, which prohibits close study of the surface. The ground has been opened by a number of prospects and a main lower tunnel, which extends 800 feet southwestward in black limestone. A brown ferruginous seam is opened, the ore from which, it is reported, shows gold on assay.

WHITEPINE CANYON.

GENERAL GEOLOGY AND TOPOGRAPHY.

Whitepine Canyon, lying next west of Thaynes Canyon, is a broad, flaring valley heading on the main Wasatch divide. It descends gradually northward to Iron Hollow, where it unites with a companion valley from the west and thence descends at a steep gradient beyond the limits of the district mapped. Its headward part, especially about the base of the slope at the southwest, is littered with glacial waste, both rock and soil. Downstream the rounded, softened profile and the distribution of float show further modification by glaciation.

The prevailing formation exposed is the Thaynes, chiefly the upper part, which occupies about the upper two-thirds of that portion of the canyon lying within the area mapped. It is succeeded by the overlying Ankareh shale, whose basset edges form the steep, partly eroded bluff on the ridge overlooking the valley from the west. At the north, capping the inclosing ridges on either side of Iron Hollow, is the massive bed of coarse white Nugget sandstone.

The prevailing dip of the sediments is 30° N. 30° W. In the northern part of the canyon little deformation was noted. At the south, in the zone adjoining the intrusive rock and within the path of the great fracture zones of the district, the beds are considerably deformed. A northeast dike of diorite porphyry cuts across the southeast head slopes; a short, narrow dike parallel to that crosses the crest of the main divide about 1,000 feet west; and north of Scott Peak coarse diorite porphyry again outcrops. Further, the Crescent fault zone not only appears to play an important part in determining the gap at the head of Thaynes Canyon, but parts of it doubtless fault the ridge at the southeast head of Whitepine Canyon. In the gap just west of this canyon a strong zone of N. 40° E. fissures crosses the divide and together with other faults seems to account for the elevation of upper members (Pentacrinus zone) of the Thaynes formation from the west side of Thaynes Canyon on the Silver Bell property to the base of Scott Peak, on the spur at the southwest head of Whitepine Canyon.

Prospecting has been done about the head of the canyon in this upper limestone of the Thaynes formation in the vicinity of intrusive rocks and along northeast fissures. Some work was being done in this locality at the time of visit. In lower Whitepine Canyon exploration of fractured ground in the highest part of the Thaynes formation was also in progress. Such mineralization as has been found is, so far as observed, along northeast fissures in the vicinity of porphyry.

WESTERN MONITOR SHAFTS.

The Western Monitor shafts are situated at the head and near the eastern edge of Whitepine Canyon, above the road. The property is developed by a couple of shafts which are down approximately 50 feet. The surface in the vicinity is strewn with fragmental rock of glacial or landslide origin, and the shafts penetrate this material to bedrock, which is a calcareous sandstone. Mineralization, as shown by the dumps, has formed calcite veins bearing pyrite. The pyrite in places makes off from the veins into the country rock as if by replacement, and pyrite crystals are also scattered through the sandstone as impregnations distinct from veins.

PARK CITY AND MIDNIGHT SUN PROPERTY.

The Park City and Midnight Sun property is situated on the east side of Whitepine Canyon north of the Silver Bell and D. & M. properties. It comprises eight claims (160 acres), which were consolidated in 1899, when the present company was organized. Its development consists

of a shaft sunk some 40 feet on a ledge and a long lower tunnel, which was being driven southeastward to open the ledge in depth. Members of the Thaynes formation, here dipping north-northwest, are cut at the south by a northeast dike of diorite porphyry and are overlain at the north by the sandy lower members of the Ankareh shale. At the time of visit work in the lower tunnel had progressed under contract many hundred feet toward its objective point. It was stated by the company that assays of material from the bottom of the shaft yielded good results.

SILVER STAR SHAFT.

The Silver Star prospect is situated on the eastern slope of Whitepine Canyon on the Thaynes road. The workings consist of a shaft about 50 feet deep, but it was not accessible when visited. The material on the dump indicates, however, that all the workings are in limestone of the Thaynes formation, and have as yet penetrated little or no mineralized rock.

MISCELLANEOUS PROSPECTS.

A group of claims named Lady Louise, Sophia, Terrible Swede, and Great Western is situated at the head of Whitepine Canyon on the west side and a short distance beyond the west end of the upper Whitepine road. This group is being prospected by a tunnel extending 200 feet westward into the canyon wall and then forking into short northwest and southwest drifts. At the face of the latter a winze has been sunk 15 feet. The surrounding rocks, both on the surface and underground, are limestones of the Thaynes formation, which at this point slopes gently northwest. Slight northeast fissures are present and are best shown in the southwest drift, but mineralization is insignificant and is limited to calcite veins, which in places inclose fragments of limestone. These veins are scantily stained by iron oxides and have suffered movement since deposition. Such veins are probably being formed continuously in brcken limestone country rock by percolating ground waters.

BIG COTTONWOOD CANYON.

GENERAL GEOLOGY AND TOPOGRAPHY.

The Big Cottonwood is one of the master canyons of the Wasatch Range. From the main divide in the extreme southwestern part of the Park City district it descends westward, cutting deeply through the range to the Jordan Valley at its western base. The stratified formations of intensely complex structure, the extensive intrusive masses, and the varied ore deposits in this canyon, which were studied in connection with the present survey, are of fundamental importance. The standard stratigraphic section (p. 50), which forms the basis for mapping these formations in the adjoining disturbed Park City area, was measured on the north side of Big Cottonwood Canyon along the spur east of Mule Hollow. Aside from that section, however, the geology of this canyon, which lies outside of the region under consideration, can not be presented here except in the briefest and broadest general outline.

In general, the sedimentary series traversed by this canyon comprises formations from the Triassic to the pre-Cambrian, and it dips as a whole toward the north. The Ankareh shale (marine Triassic) lies at the head of the northeast tributaries and the Thaynes formation (also Triassic) at the east head of the main canyon. Westward successively lower formations wall the canyon, the Park City formation (Permian?), the Weber quartzite (Pennsylvanian), and earlier Carboniferous limestones. The last form the wall nearly down to Argenta Canyon. At the big bend in the canyon several miles downstream a profound fault drops the Triassic on the west against Carboniferous limestone. Below the bend the top of the Weber quartzite outcrops in prominent ledges, and beyond ledges apparently of Carboniferous limestone stand out. In a strong canyon entering from the south the outcrops of Carboniferous limestone are underlain successively by quartzite, limestone, and apparently Cambrian quartzite. Toward the west the main canyon descends through the great section of Cambrian quartzite[1] into the pre-Cambrian metamorphic series and comes out upon the Pleistocene deposits in Jordan Valley.

[1] Walcott, C. D., Second contribution to the studies on the Cambrian faunas of North America: Bull. U. S. Geol. Survey No. 30, 1886.

The broad amphitheater at the head of this remarkable canyon has been eroded in the great east-west zone of intrusion that traverses the Oquirrh and Wasatch Ranges—the Little Cottonwood mass of granite, which stretches from a point near the mouth of Little Cottonwood Canyon for several miles up to its head. At Alta the granite gives way to a granodiorite, which continues east-northeast at the head of Little Cottonwood Canyon, forms the divide between that and Big Cottonwood, and stretches across the broad amphitheater into Snake Creek. This in turn gives way farther northeast to the finer-grained, more basic diorite that forms Clayton Peak and stretches along the southern part of the Park City area.

The eastern head of Big Cottonwood Canyon lies along the northern contact zone of these dioritic and granitic masses with the sedimentary formations on the north. Only the highest part of this basin on the contact lines within the area of the Park City map may be seen near the southwest corner. In the limestone contact zone some prospecting was done in early times and several properties were being developed at the time of the present examination. One of these, the Scottish Chief, lying just beyond the limits of the area mapped, has throughout its history been most closely associated with the Park City district, and is therefore considered in the present report.

SCOTTISH CHIEF MINE.

The Scottish Chief mine is situated high on the southwestern slope of Scott Hill overlooking Big Cottonwood Canyon. It embraces the old Insley property, on which, it is stated, considerable money has been expended in former years and from which some excellent ore was extracted. In the fall of 1902 the company operating under the present name was organized. Owing to the outlying situation of the mine and the difficult approach to it, the cost of transportation was high, and unusual difficulty was experienced in obtaining help and materials; nevertheless work was pushed with great energy. At the time of one visit deep snowdrifts almost shut off the mine from the outside world, and a little later a party of officers of the company intending to visit the property were forced to abandon the attempt after extreme exertion caused by the deep snow.

When the present company took over the mines, the main underground working was an incline 200 feet long with laterals, and there were some surface prospects. Within the next 12 months the incline was driven another 200 feet and additional work was done on two levels running east. Below the third level an incline descends 93 feet.

In the fall of 1902 ore found in the course of this work was shipped and in 1903 shipments were made in September and October.

The Scottish Chief ground embraces highly metamorphosed limestone members of the Thaynes formation. Thus argillite, quartzitic sandstone, and marble, which indicate intense alteration, are present. In the gap at the north are sandy and shaly beds, and at a shaft just north of the peak of Scott Hill is coarse diorite porphyry. The general dip of these sediments is 23°–30° N. Fracture zones traverse these rocks on northeast, north, and northwest courses and are the loci of faults, which may aggregate considerable amounts.

The particular sequence of members that incloses the ore underlies the Pentacrinus-bearing limestone and is composed of a considerable thickness of cream-colored thin-bedded calcareous shales, a 3-foot bed of dark-gray crystalline limestone or marble, and several sandy beds made up in places of clear quartz. This series is cut by many faults and here and there displacement is observable. Traversing the upper levels and the winze is a fault on which ore is bent but not broken, and on a lower level at the east a fault offsets ore 1 to 3 feet down on the west. At the head of the east winze descending from the third level is a triplicate series of fractures trending N. 36° E. that apparently fault the ore bed out toward the east and are followed down by the east winze. It seems clear that much of the faulting is later than the ore and that the displacement at some points is downward on the west.

The croppings of ore appear in the rear of the bunk house along the upper part of a bed of coarse blue-gray marble, which lies under dense, finely banded gray-white metamorphic limestone and over a siliceous footwall in marble, which in some places is flinty and in others sandy. In these croppings galena altered to anglesite and cerusite occurs in calcite, garnet, and limonite

in an 8-inch bed in country rock of coarse marble. A bed 2 feet lower shows copper stains in calcite. This ore-bearing bed has been systematically followed underground and found to dip 23°–30° N. 15° E. The general ore bed or zone is 24 to 30 inches thick, and the ore band within this bed averages 3 to 6 inches. The ore is further localized into a sinuous pod-shaped shoot, which within the general zone pitches 30°–45° E. In its descent from the surface it has been caught on the first, second, and third levels, and was found at one point to be about 25 feet wide on the plane of the ore bed. It had not been developed sufficiently at the time of visit to reveal its dimensions, and its course beyond the triplicate zone of faults at the head of the east winze below the third level also remained to be determined.

The ore yields lead, silver, copper, and gold. Lead is derived from the galena, anglesite, cerusite, and massicot, and possibly some pyromorphite. The source of the copper is seen to be mainly copper pitch, chalcopyrite, chrysocolla, and malachite. Silver, which seems to run highest in the oxidized ores, lies in part in the lead. It was stated that native silver had been observed at one point on the third level east, but nothing which could be recognized as such could be found at the time of visit.

The grade of the ore is consistently reported to be high. No samples were taken and assayed. Some of the picked carbonate lead-silver ore might well run 65 per cent of lead, and some of it is stated to have yielded 300 ounces of silver and $2 in gold to the ton.

SOUTHERN AREA.

TOPOGRAPHY AND GENERAL GEOLOGY.

The western part of the southern area of the district forms a distinct topographic and geologic unit. The eastern spur of the Wasatch Range, in which the mines of the district have been opened, trends southeastward across the area, and its steep south slope delimits the western part of the area. This is, in turn, made up of two parts, the mountainous, ledgy, ragged western part and the low rolling plain of the eastern part. The former is the Clayton Peak mass and the latter is Bonanza Flat.

This topography is an expansion of the underlying rock structure. The Clayton Peak mass is made up throughout of intrusive diorite, which forks eastward across the sediments and metamorphoses them, particularly the limestone, on both the north and the south. These sediments thus rendered more enduring constitute the backbone of this district. The intrusive rock descends eastward to Bonanza Flat, and on the east the series of intrusives is continued by diorite porphyry. The head and sides of the valley descending from Clayton Peak have been carved and polished by ice. Shallow rock basins at the bases of the head slopes have been scoured out and are now filled with mountain lakelets that overflow rock rims. Bowlder trains and lateral moraines rim the upper valleys and series of frontal moraines loop across them at short intervals.

Some prospecting has been done within the area of diorite, mainly along fissures and joint or sheeting planes that show some bleaching or rusting, but so far as could be observed without significant results. The contact zone of limestone bordering the mass on the south and north has also been explored through crosscut tunnels, but no results of commercial importance have been obtained. The principal mining operations in this general area have been on the lowland beneath Bonanza Flat or contiguous ground.

BONANZA FLAT.

GEOLOGIC FEATURES.

The area known as Bonanza Flat is geologically one of the most interesting within the entire district. The flat itself is covered with débris, mainly glacial, from its head near the Bonanza-Brighton Pass to and beyond the limits of the area shown by the map, the mass forming Lone Hill being the only bedrock outcrop. The distribution of this material is described under "Glacial deposits" (pp. 60–62). In general, the ground moraine formed by the mass as a whole bears lateral moraines and excellent frontal moraines, especially in the southern part.

This blanket covers most of the contact of the diorite with the sediments on the north, also the eastern periphery of the diorite and the western edge of the diorite porphyry stock. The exact positions of these important geologic features and the geologic relations between them beneath this cover are hence known only incompletely and approximately.

The solution of important economic problems connected with these features has been sought through several series of workings. These have revealed the occurrence of some irregular masses of rich ore in the contact zone immediately south of Anchor Gap, of occasional bits of copper mineral in vein rock in intrusives, and of some rusting along fissures.

WHITE PINE MINE AND JONES SHAFT.

The White Pine, one of the old pioneer workings in the district, situated at Anchor Gap, is included in the Daly-Judge ground and is described in the section on that property (p. 155).

The Jones shaft is also embraced in the extensive holdings of the same company. It is situated out on the main bottom of Bonanza Flat, three-tenths of a mile due south of Anchor Gap and one-tenth of a mile south of the main Bonanza road from Park City to Big Cottonwood Creek. It is down a few hundred feet, and little drifting is reported to have been done. The story of its discovery is that in the early eighties, while carrying out a timber contract, Robert Jones was snaking logs across this spot. One became wedged, and to release it Jones broke an obstructing rock and to his amazement exposed a mass of solid galena. The Jones Bros. followed up this discovery by laying claim on the ground and sinking the shaft known by their name to a depth of 200 feet. Since that time the shaft has been sunk farther, and it is stated that a considerable flow of water has been encountered.

The ground lies along the general contact of the Clayton Peak mass of diorite with the sedimentary Park City formation. In this particular locality a few outcropping ledges show that the diorite cuts across the limestone very irregularly and metamorphoses and mineralizes it. Thus, on the low spur west of the shaft, against tongues of diorite, contact-metamorphic silicates are developed. The ore uncovered at the surface, which was doubtless a contact deposit, it stated to have continued in the ground opened by the shaft. It afforded a good profit to the Jones Bros., but later operations were stated to be unsuccessful.

WEST QUINCY PROPERTY.

The West Quincy property is situated in the northern part of Bonanza Flat, adjoining the Lucky Bill and Little Bell ground on their southwest side and almost abutting on the south side of the Daly West and the east side of the Daly-Judge. It comprises five large claims (90 acres) which extend in a general southwesterly direction down from the main divide and out upon the flat.

The J. I. C. Co. was organized in 1902, financed largely, it is understood, by Scotch capital, to take up and explore ground in which some of the ore zones of the great properties adjoining might continue. Under an energetic management, living quarters, a complete hoisting outfit, and a powerful pump were speedily installed, and sinking was begun. The history of the work for the first few years is a record of persistent endeavors to open the ground at depth and explore it in spite of a tremendous flow of water. After accomplishing considerable sinking and some drifting, the company was reorganized and incorporated under the laws of Utah as the West Quincy Mining Co. In 1906 the Boulder Basin group of about 20 claims lying south of the original location on Bonanza Flat was added to this property.

The development includes a double-compartment main shaft more than 600 feet deep, drifts on the 440-foot level southeast and northwest of the shaft, a long drift from the Little Bell shaft at the 1,016-foot level to a point within 150 feet of the West Quincy shaft, where work was stopped by water, and an intermediate level about 60 feet above the 440-foot level connected with it by a raise. In 1906 boring with a calyx drill from the 440-foot level was undertaken and at last report had reached a depth of 1,250 feet.

The surface of this ground is largely hidden beneath the extensive glacial deposit that blankets the bottom of Bonanza Flat. On the higher part, however, adjacent to the main road, the north-south contact of the extensive body of diorite porphyry with the metamor-

phosed sediments on the west appears above the glacial blanket. The greater part of the porphyry exposed is of the coarse diorite-porphyry variety, though immediately east of the shaft at some prospects apparent modification and possible transition stages were observed. The form of this intrusive mass has not been demonstrated, but its exposure indicates that in a part of its extent at least it is a comparatively flat body, though with feeders. The metamorphic sediments include marble, argillite, and the various types of contact-metamorphic limestones. The dip near the shaft is 50° N. 75° W. Owing to the intense alteration and to deformation by intrusion and faulting, stratigraphic identification in this region is exceedingly difficult. Just north of the divide at the head of the gully metamorphic shale lies immediately against the porphyry and metamorphosed limestone. The shale is probably the Woodside and the limestone the Thaynes, and this is as closely as the formations in this region may now be correlated.

The shaft descends in limestone, except for certain siliceous members, to the 600-foot level, where a dioritic intrusive rock is encountered. The 440-foot level is almost entirely in arenaceous sediments, the workings toward the north being mainly in quartzitic brown sandstone with a little altered calcareous shale and the long drift south-southeast uniformly cutting argillite (metamorphosed shale). Northeast of the shaft a narrow northeast dike of a dioritic intrusive is cut, and a similar one occurs at the extreme southeast. About 750 feet from the shaft a 15-foot northeast dike is found. This appears to be either an arm of the main diorite mass or a fine-grained basic segregation from the diorite porphyry. At the head of the 60-foot raise on a northeast fissure from the workings north of the shaft a sedimentary contact occurs between a buff metamorphosed limestone or impure marble hanging wall and a fine-grained brown sandy sediment. This contact dips 27° N. 66° W. and is marked by about 6 inches of stained iron and copper material. It is a favorable point for prospecting. This is claimed to be the ore-bearing and contact zone occurring in the Quincy and Daly West and certainly exhibits some lithologic resemblance to that zone. Definite correlation of these commercially important members, however, would require much systematic underground development work. Even then the complicated deformation by faulting and intrusion might prevent positive determination.

On the 400-foot level the sediments dipping northwest are traversed by northeast fissures, a strong one north of the shaft, trending N. 58°–60° E. and dipping 60° SE., and three or four south of it, trending more nearly east-west and standing steeply. The latter contain barren breccia stained in places with iron or manganese.

At the foot the shaft cuts about 40 feet of a fine-grained dioritic intrusive rock similar to that in the dike on the 440-foot level. In a short drift on the 600-foot level this rock is seen to be much altered and thoroughly impregnated with cupriferous pyrite. At the station the intrusive carries veins of partly crystallized calcite, in which occur small blotches of gray copper and chalcopyrite. The record of the drill hole driven from the 440-foot level shows blue carbonaceous limestone, marble, and fine-grained metamorphic limestones to a depth of 1,250 feet, probably the Park City formation. Thus, although no ore bodies had been opened at the time of visit, the mineralization on the contact at the head of the raise north of the shaft and the disseminated cupriferous pyrite and blotches of tetrahedrite in the fine-grained intrusive mass on the 600-foot level presented possibilities which deserve thorough prospecting.

SOUTH QUINCY TUNNELS.

The South Quincy property, formerly the Bonanza Consolidated, is situated in Bonanza Flat on Lone Hill. The property is developed by several tunnels and prospects scattered over the south side of Lone Hill, but most of them are small or inaccessible, and the most important one now open lies on the northeast side of the hill. This tunnel runs southwest in a fairly straight line for 850 feet, and near its face are three short drifts aggregating 300 feet. Lone Hill is made up of two rock formations—the Weber quartzite, which forms the southern two-thirds of the hill, and diorite porphyry, which forms the northern third. The contact between the two extends roughly east and west and is lost at both ends beneath the glacial gravels of Bonanza Flat, which wrap about the entire hill. The quartzite, which at places dips to the west at a low

angle and contains thin layers of limestone, is traversed near the contact by northwest fissures. One in particular may be followed on the surface for several hundred feet as a broad band of brecciated quartzite cemented by iron oxides. This zone is well opened by small shafts and prospects.

The rocks revealed in all the tunnels are either quartzite or porphyry. The main tunnel passes the porphyry contact about 400 feet from the portal and penetrates a 30 to 50 foot band of breccia at about 600 feet. This is probably the same zone as that which outcrops in the quartzite on the surface, as described above. Aside from this breccia zone and a northeast fissure that enters the face, northwest fissures prevail, one following the contact between the quartzite and the porphyry.

Another tunnel on the south slope of the hill penetrates quartzite for at least 130 feet, beyond which it is caved in. The dump, however, shows limestone fragments, which probably came from some point near the face. Northeast fissures cut this tunnel, the principal one being 100 feet from the portal.

Mineralization is prevalent. The breccia zone on the surface contains some crushed crystals of calcite and quartz with heavy stains of iron oxides. A northwest 3-foot fissure near the face of the main tunnel was somewhat mineralized with galena and carbonate of copper. Material from this zone is reported to have yielded 10 ounces of silver to the ton and 10 per cent of lead. Some of the surface prospects near the other tunnel showed crushed quartzite stained green with copper. No ore has been shipped from the property.

SUPERIOR TUNNELS.

The Superior group is situated on the east slope of Bonanza Flat southeast of Lone Hill. The group is developed by several tunnels entering the slope in directions ranging from northeast to southeast. Some were inaccessible, but those visited are under 200 feet long, except one which is about 850 feet. The surrounding rocks consist of metamorphosed limestones and quartzites, presumably the lower part of the Carboniferous, which are extensively invaded and severed by intrusions of diorite porphyry. Quartzite occurs near the crest of the ridge, but the intercalated limestones are most common on the slopes near the tunnels. The regular dip of these beds has been greatly disturbed by the igneous intrusions. In general the dips range from 40° to 60° NW. or NE. The contacts between the beds and the porphyry, especially on the slope, are extremely difficult to determine owing to the heavy cover of float, which in several tunnels is 20 to 30 feet deep. The workings appear to lie near the contacts and many of them penetrate the rocks on both sides. The main tunnel exhibits all three rocks. For the first 550 feet it is in quartzite dipping 45° NE. This is interrupted for a space of 200 feet by a dike of diorite porphyry, but beyond that it is continued again toward the face until severed by a N. 75° W. fault. This brings up against the quartzite some limestone beds which form the face of the tunnel. The northwest drift near the portal also cuts the porphyry dike, which therefore would seem to take a roughly north-south direction. The rocks, however, are not so profoundly broken as would be expected from such extensive intrusions; indeed, the fissures are in the main slight and fall into northeast and northwest groups, of which the former is the younger. Mineralization also is slight, being observed only along a 2-foot fissure in a short tunnel near the northern margin of the property. This exhibited green and brown stains of ferruginous compounds and also crystals of zinc blende. No ore was observed.

TATTERSALL PROSPECTS.

The Tattersall group is situated on the south side of Bonanza Flat, 2 miles due south of the Daly Judge shaft and 1 mile south-southwest of Lone Hill. On a low-lying spur quartzite rises above the glacial material, which occupies the main valley bottom. This formation has been explored by a main tunnel, prospect tunnels, and prospect shafts. The flat top of the spur exposes a strong clean fissure traversing the quartzite in a N. 65°–85° W. direction. The main tunnel, which was not open to inspection at the time of visit, was reported to be 100 feet in length. All the work, so far as could be judged from the dumps, has been done in quartzite, except some that cut thin intercalated limestone. No ore was observed.

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