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BOULDER

R. D. GEORGE, State Geologist

BULLETIN 17

TWIN LAKES DISTRICT OF COLORADO

By
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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, November 27, 1918.

Governor Julius C. Guntèr, Chairman, and Members of the Advisory Board of the State Geological Survey.

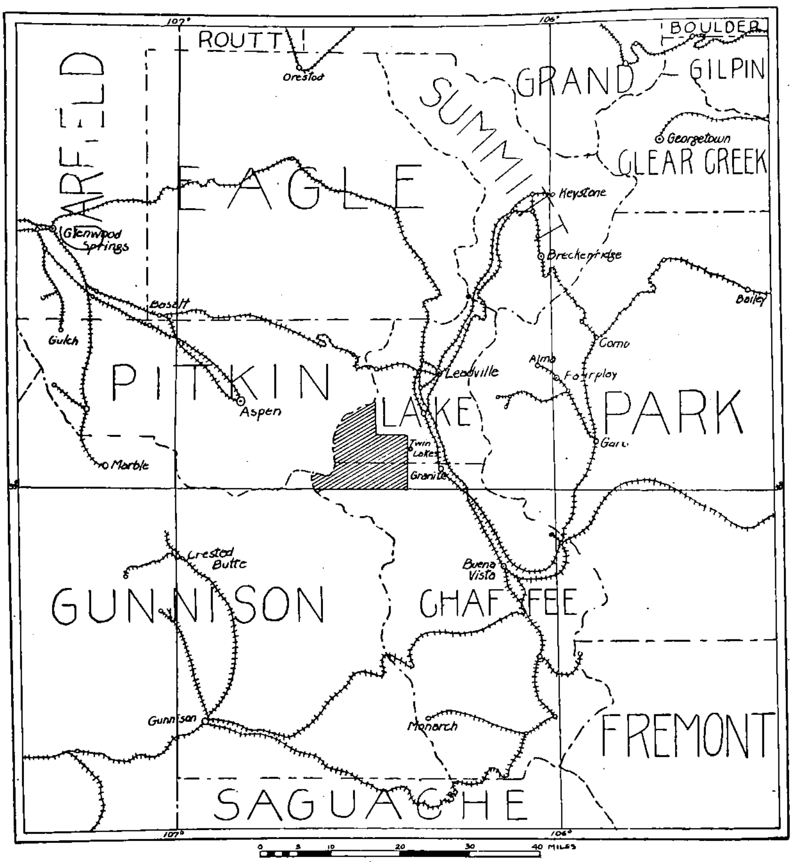
Gentlemen: I have the honor to transmit herewith Bulletin 17 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

CONTENTS

ILLUSTRATIONS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Geology and Ore Deposits of the Twin Lakes District of Colorado

CHAPTER I

INTRODUCTION

FIELD WORK AND ACKNOWLEDGMENTS

The field work whose results are discussed in the following pages was done during the summers of 1915 and 1916. The writer worked alone during the first season, but in 1916 was ably assisted by Mr. John T. Lonsdale.

The topographic base map was prepared by enlarging, photographically, the desired portions of the Mt. Jackson and Leadville sheets of the United States Geological Survey. The Mt. Jackson sheet was found to be very accurate, but the Leadville sheet represents only approximately the actual configuration of the surface. On this sheet the boundaries of the formations have been made to correspond to the topography insofar as possible, but it is realized that in so-doing the actual positions of the boundaries have been moved.

It would be impossible to mention separately each of the persons who has been of assistance in the collection of data in the field. The people of the district have been uniformly courteous and hospitable at all times. To all who have thus aided him the writer desires to express his sincere thanks.

Professor R. D. George has given valuable advice and assistance, both in the field work and in the preparation of the report. Professor G. F. Kay, of the University of Iowa, and Professor R. D. Crawford, of the University of Colorado, have very generously given advice and assistance in many ways.

LOCATION AND AREA

The district discussed in this report embraces an area of about 85 square miles, situated in the southwest corner of Lake and the northeast corner of Pitkin counties. The boundaries are irregular and have been drawn in such manner as to include practically the entire basin of Lake Creek and the territory for which the Lake Creek trail serves as a highway.

The southern boundary of the west half of the area is the parallel 39° 00′ north latitude, and its northern boundary parallel 39° 10′. The meridian 106° 30′ west longitude passes through the area near its center.

For the purposes of this report the Twin Lakes district will be considered as including all territory within the Lake Creek basin, in addition to some adjacent territory which is so situated that the Lake Creek trail forms its natural outlet to the railroads. Such a definition permits the inclusion of the following general groups of claims:

1. The Twin Lakes group. Located near the mouth of Lake Creek, near the village of that name. Both lode and placer claims are included.
2. The Lackawanna Gulch group. Those claims which lie in Lackawanna Gulch and on Mounts Champion and Lackawanna and near Independence Pass.
3. Bull Hill group. A group of claims lying along the divide between Monitor and Black Cloud Gulches.
4. Red Mountain group. A large number of scattered claims in Sayers and Peek-a-boo Gulches and along the South Fork of Lake Creek.
5. Isolated claims lying between the above-mentioned groups.

The entire district is in Lake and Chaffee Counties, lying partly in the southwest corner of Lake and partly in the northwest corner of Chaffee County.

ROADS AND TRAILS

Access to the Twin Lakes district is had by means of the Lake Creek trail, which is passable for wagons as far as the mouth of Lackawanna Gulch on the North Fork, and to the Bwlchgoch Mine on the South Fork. None of the trails leading from the main trail into the tributary gulches is suitable for the passage of wheeled vehicles, and material must be transported through them on pack animals.

State funds are now being made available for the improvement of the Lake Creek trail from Twin Lakes to Brumley, and for constructing a new trail from that point through Hunter or Independence Pass to connect with a similar trail which follows the valley of the Roaring Fork from the foot of the pass to Aspen. When both of these projects are completed it will be possible to drive an automobile from Twin Lakes to Aspen without encountering any troublesome grades.

This improved highway should be of great advantage in the development of the mineral as well as the scenic resources of the Lake Creek district.

CLIMATE

The Twin Lakes district is an area of high altitudes, the lowest point within its boundaries, near Twin Lakes, being 9,200 feet above sea level. Low temperatures prevail during the greater part of the year and the conditions during the winter months are such that work on most of the properties must be abandoned. The snowfall is very heavy, and as a rule the Lake Creek trail is closed to wagon transportation from December to June. During many years snow lies all summer in protected spots on the peaks.

The Mount Champion mine is operated throughout the year, fuel and supplies being transported to it by wagon or sled up the valley of the Halfmoon to the foot of the mountain, and thence up to the mine (altitude 13,500), by cable tram.

During the summer the climate of Twin Lakes and its vicinity is delightful. The days are clear and warm, the nights cold, and the skies are cloudless most of the time. The sudden rains, which are of almost daily occurrence farther up the valley, are experienced much less frequently near the lakes.

In the higher parts of the district hard frosts occur every night throughout the summer, and except during the months of July and August the climate is rather severe. Sudden showers are of almost daily occurrence during the summer.

NATIONAL FORESTS

The entire district lies within the boundaries of the Leadville National Forest. The Forest Service, owing to insufficient appropriations for the purpose, has been unable to build permanent trails, but has marked the existing trails in such manner that they may be followed readily.

Each season from ten thousand to fifteen thousand sheep are ranged in the gulches tributary to Lake Creek. This grazing is under the direction of the Forest Service. In addition to the sheep a few hundred head of cattle are pastured. Generally the sheep range lies west of a line drawn through the middle of Sayers Gulch to its junction with Lake Creek, thence to Everett, and thence up the North Fork of Lake Creek to its head.

HISTORY

EARLY EXPLORATION

The name of the man who first entered the Twin Lakes district is not a matter of record, nor is the date of his visit known. Fremont in 1845 reached the Arkansas River near the southern end of South Park, and followed it to its head, where he crossed the Sawatch Range at what is now called Tennessee Pass and journeyed westward down the valley of Eagle River. Accounts of this exploration make no mention of Lake Creek Valley, and it is improbable that either Lieutenant Fremont or any of his party advanced beyond the great moraines which surround its mouth. During the years following, until the great Pikes Peak excitement in 1849, there is no doubt that many hunters and trappers visited the Arkansas Valley, then the hunting grounds of the Utes and Arapahoes, but of these visits there remains no record whatsoever.

In the spring of 1860 gold was discovered in the Cache Creek gravels and a number of miners stopped there for a time, but soon left on receipt of news of the rich strikes in California Gulch, near what is now Leadville. It was at about this time, so far as known, that the first exploration of Lake Creek must have occurred. By 1865 Dayton (now Twin Lakes), at the head of Upper Twin Lake, had a population of 400-500 people.

Although the valley up to 1860 had been traversed by few, if any, white men, it had been for years the route of one of the principal Indian trails of the Colorado Territory. From the Arkansas Valley this trail wound among the moraines at the mouth of the creek, entering the valley near the head of the upper lake and following Lake Creek and its South Fork to Lake Creek Pass, south of the Bwlchgoch mine, where it crossed the Sawatch Range. From this pass it followed the Taylor and Gunnison rivers southwestward to the Grand. The trail is still in use as far as Lake Creek Pass, but beyond that point it has been little traveled for many years, and can be followed only with some difficulty.

About 1865 rumors of a rich placer strike near the mouth of Sayers Gulch caused the settlement of several hundred people in that vicinity. The remains of numerous cabins and the yellow gullies that indicate the location of the sluices are all that can be seen of this embryo city. The rumors proved unfounded and gold in paying quantities was never found.

In 1867 O. J. Hollister visited many of the mining districts of Colorado and wrote[1] the following description of the mines of Lake Creek:

Lake Creek empties into the Arkansas at the upper end of Cache Creek Park. It is five miles from its mouth to the head of the Twin Lakes, which we have referred to before. They are beautiful sheets of water and full of trout. South of them the range rises abruptly from their very edge; on the west there is a large bottom and here is Dayton, the county seat. Hence to the Red Mountain at the extreme-source of the Creek is about fifteen miles, in a west-southwest direction. Red Mountain seems to be in a belt of lodes, some three miles in width, which here crosses the range in the true course, northeast and southwest. From the top of the Red Mountain at the head of the left fork of Lake Creek other red mountains can be seen both to the east and to the west. Eight miles west in an air line a Boston company did some work in 1866, finding similar ore to that found here. This point is about one hundred miles west of Pikes Peak. The crest of the mountains crossing the belt is mostly a gneissoid rock, sometimes a syenite. That has been broken and worn off in places exposing an iron conglomerate of unknown thickness, with veins of purer pyrites bursting up through it without much regard to the proprieties. The pebbles of which the conglomerate is composed are quartz, and carry as much iron as the cement quartz which holds them together. Where the cap has crumbled or been washed off from the conglomerate, exposing it to the elements, the iron has become an oxide, giving the outside of the quartz a brilliant red color. This is noticeable as far as the belt can be seen, and the width so exposed is not less than one mile. In the streams and where the creek escapes from the mountains, numerous well defined lodes have been discovered, not greatly different in width, lineal extent and character of ores, from those of other parts of the territory. Like them, too, they vary in richness. Some of them are absolutely barren and some contain $100 gold to the ton, as tests of which we were personally cognizant have indicated.* It is believed the requisite capital has been secured to establish at once one or two stamp mills in this, called the Red Mountain District. There is not now a quartz mill in the county, nor a shaft more than thirty feet in depth, although the Berry tunnel near the head of California Gulch has been driven one hundred feet. In this a pay vein six feet in width is claimed. The ore assays seventy or eighty dollars a ton in gold and silver and is very rich in copper. But nothing very definite with reference to the quartz mines of the district is known.

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[1]Hollister, O. J., The Mines of Colorado, pp. 314-316, Springfield, Mass., 1867.

*Ex-Secretary Elbert, of Colorado, had forty-six samples of ore from forty-three of these lodes assayed by Behr and Keith of Black Hawk. They varied from $59 to $441 per ton, averaging $138.25. One sample yielded seventy per cent. copper.

Professor John J. Stephenson, of the Wheeler Survey, visited Lake Creek Valley in the season of 1872-3 and studied the glacial phenomena with some care.

From 1872 to 1878 Lake Creek was several times traversed by members of the Hayden Survey, including F. V. Hayden and A. C. Peale, both of whom have written accounts of the geographic and geological features. Hayden appears to have been particularly impressed by the beauty of the scenery of the Sawatch Range, and in addition to his official reports he has published a number of articles dealing with this feature. The remarkable glacial sculpture of the Lake Creek Valley formed the subject of several interesting papers.

In 1879 silver-bearing ore was found in the Paleozoic limestones near Aspen, on the western side of the Sawatch Range. As the Denver & Rio Grande Railroad at that time extended only as far as Granite, all supplies intended for Aspen and other parts of the Roaring Fork Valley were hauled by wagon from the end of the railroad. A road was built up Lake Creek Valley, following the old Indian trail to the forks of the stream, and thence up the north fork to Brumley, where it leaves the valley floor and climbs up the steep western wall to Mountain Boy Park. From the park the road ascends rapidly to the broad crest of the divide in Independence or Hunter Pass, at an altitude of 12,226 feet. A steep trail leads from the pass down to the valley of Roaring Fork, which it follows by an easy grade to Aspen. The total distance from Granite to Aspen by this trail is about forty miles, and to traverse it one must climb from an elevation of 9,000 feet at Granite to 12,226 at the summit of the pass.

Until 1887, in which year the Denver & Rio Grande extended its line from Leadville to Aspen, regular freight and passenger stages made the trip across the range over the Lake Creek trail. It was customary to change horses at rather short intervals and a number of change stations, usually with a roadhouse in connection, were established along the trail. Most important of the stations and roadhouses were the ones at Twin Lakes, Four-mile Park, Red Mountain Inn (one-half mile below the forks of Lake Creek), Myers Camp, Brumley and Independence. With the advent of the railroad on the west side of the divide the trail was no longer used, and at the present time (1916), the section between Brumley and Independence is not passable for wheeled vehicles.

Work was commenced in 1914 on a state highway which, when completed, will provide an automobile road from Leadville to Aspen, following the old Lake Creek trail from Twin Lakes to Aspen.

DEVELOPMENT

Prospecting has been carried on intermittently in the Twin Lakes district ever since the first settlement near the Lakes. Practically all of this work has been of an extremely haphazard nature, and but little real development has taken place. The mountain sides are pitted with shallow prospect holes and short tunnels, but extensive workings are few in number.

The Gordon and Bwlchgoch mines have been operated at intervals since the early nineties, sometimes with as many as thirty men employed at each place. The Golden Fleece, D. M. Elder, Eureka, Miller and the various placer prospects have at different times employed good-sized forces for a few months or even a season or two. But for various reasons, principal among which has been lack of ore of marketable grade, the properties never have been operated continuously.

At the present time the only mines which are being operated with any degree of regularity are the Mount Champion, Eureka and Fidelity. These, as well as the other properties of the Twin Lakes district are discussed at considerable length in Chapters IV and V.

PREVIOUS GEOLOGICAL WORK AND LITERATURE*

Little geological work has been done in the portion of the Sawatch Range covered by this report, and most of that has been in the nature of reconnaissance by members of the early surveys. F. V. Hayden, A. C. Peale, and F. M. Endlich visited Lake Creek in the course of the Hayden Survey and have left[2] several fragmentary and sketchy accounts of its geology. Their work furnished no detailed information.

During the summer of 1873, Professor John J. Stephenson, a member of the Wheeler Survey, visited Lake Creek, and he has written[3] an account of the glacial features near Twin Lakes.

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*See also page 14 of this report.

[2]U. S. Geol. and Geog. Survey Terr., vols. 7, 8, 1873-4.

[3]Geol. and Geog. Surveys and Explorations west of the 100th Mer. (Wheeler Survey) vol. III, 1875, pp. 440-446.

In the following thirty-one years other geologists may have visited the Lake Creek region, but if so they have left no record in the literature. But in the summers of 1904-5 detailed study of the Pleistocene Geology of Lake Creek Valley and the Twin Lakes was carried on by W. M. Davis,[4] L. G. Westgate,[5] S. R. Capps, Jr.,[6] and E. D. K. Leffingwell,[7] all of whom have published accounts of their observations. Lake Creek Valley has long been considered a classic example of mountain glaciation, and references to it are relatively numerous in geologic literature, but the articles mentioned cover practically all of the important work.

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[4]Davis, W. M., Bull. Mus. Comp. Zool., vol. 49, Geol. Series, vol. 8, No. 1, 1905, pp. 1-11. Appalachia, vol. 10, pp. 392-404. Science, n. s. vol. 25, pp. 835-836.

[5]Westgate, L. G., Journal of Geology, vol. 13, 1905, pp. 285-312.

[6]Capps, S. R., Jr., U. S .Geol. Survey Bull. 386, pp. 54-63, 1909. Abstract, Science, n. s. vol. 29, p. 946, 1909.

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CHAPTER II

PHYSIOGRAPHIC GEOLOGY

TOPOGRAPHY AND SOIL FORMATION

The Twin Lakes district is an irregular-shaped area extending from Upper Twin Lake, at the edge of the Arkansas Valley, on the east, to the crest of the Continental Divide on the west. It includes practically all of the territory drained by Lake Creek, excepting the upper ends of the long valleys heading near La Plata Peak.

The altitude of the district ranges from about 9,000 feet at Twin Lakes to 14,020 on Grizzly Peak, 14,000 on Mount Champion, 13,850 on Mount Leonard, and 13,500 on Deer Mountain. At Everett, near the center of the district and where Lake Creek divides into the North and South Forks, the elevation is but 10,250, hence the relief is sharp.

The entire Sawatch Range has been intensely glaciated and the present topography is largely the work of the Lake Creek glacier and its numerous tributaries. The main valley has been gouged out by the ice to a great depth, with the development of a typical

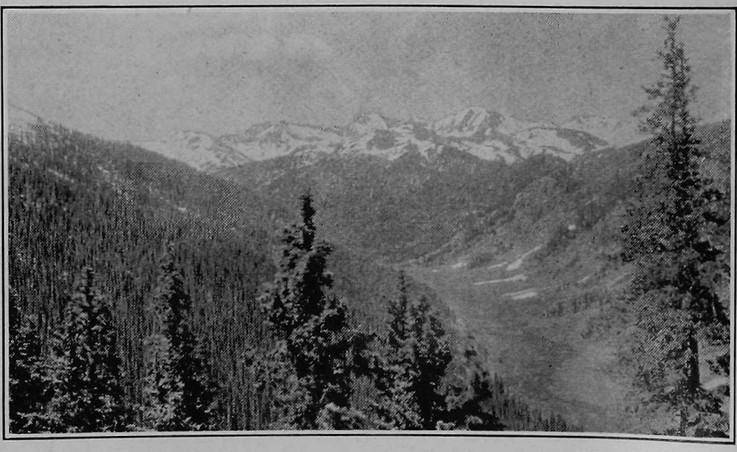

Fig. 2. Valley of Lake Creek; looking south from Mount Champion. This is a typical U-shaped, glaciated valley.

U-shape. The tributary gulches have also been glaciated, though less intensely. They now form hanging valleys, whose upper ends broaden into great cirques. The walls of both the main valley and the tributary gulches are everywhere steep, especially in that part of Lake Creek Valley below Everett, where the massive quartz monzonite porphyry has suffered but little weathering since the disappearance of the ice. It yet remains almost bare, with polished and grooved surfaces only slightly mantled by later rock waste.

A striking feature of the Sawatch Range is the preponderance of broad, smooth summits among the many lofty peaks. Hayden[8] called attention to this character, but offered no explanation for it. Ordinarily the peaks and divides above intensely glaciated valleys present a more rugged, serrate outline, in marked contrast to the smoother topography below. The Sawatch peaks are, however, generally smooth, bearing sufficient soil to support a considerable growth of grass and some low shrubs. Mechanical disintegration, due largely to temperature changes and to wedgework of ice, is the predominant process of weathering, and this usually tends to produce very different topographic surfaces.

It is obvious that a large amount of soil has been produced since the disappearance of the glaciers, for the cirque basins are in most instances filled to such an extent that bogs have formed, while thick layers of soil are found also on many of the divides. On the broad divide of Hunter Pass, for example, are several small lakes, the largest of which covers perhaps five or six acres, and extensive bogs are found in Lake Creek pass and in the pass at the head of the Frying Pan. In all such places the soil is several feet thick and supports a luxuriant growth of coarse grass and shrubs. The soil which now covers the floors of the cirques may have come in part from the sides and from the surrounding peaks, but that which now lies on the divides must have originated there.

The sod-cap is the result of excess of weathering over transportation, but the causes of this excess are not entirely clear. Daly[9] after studying similar phenomena in the Cordilleras, concludes that the tree-line has been the dominant influence. The streaming of rock waste is vastly greater above than below tree-line, and whereas the removal of waste near the crest aids disintegration by constantly exposing fresh surfaces to the weathering agents, the talus streams, halting at or just below tree-line, bury and protect the bedrock at that level. The result, as shown on an exaggerated scale

[8] U. S. Geog. and Geol. Survey Terr., 7th Ann. Rept., 1873, p. 48.
[9] Daly, R. A., Canada Dept. Mines, Geological Survey, Memoir 38, 1912, pp. 638, 639.

in Figure 3, is the gradual flattening of the summits to such a degree that considerable thicknesses of soil may accumulate, a sod develop, and chemical weathering agencies gradually become predominant.

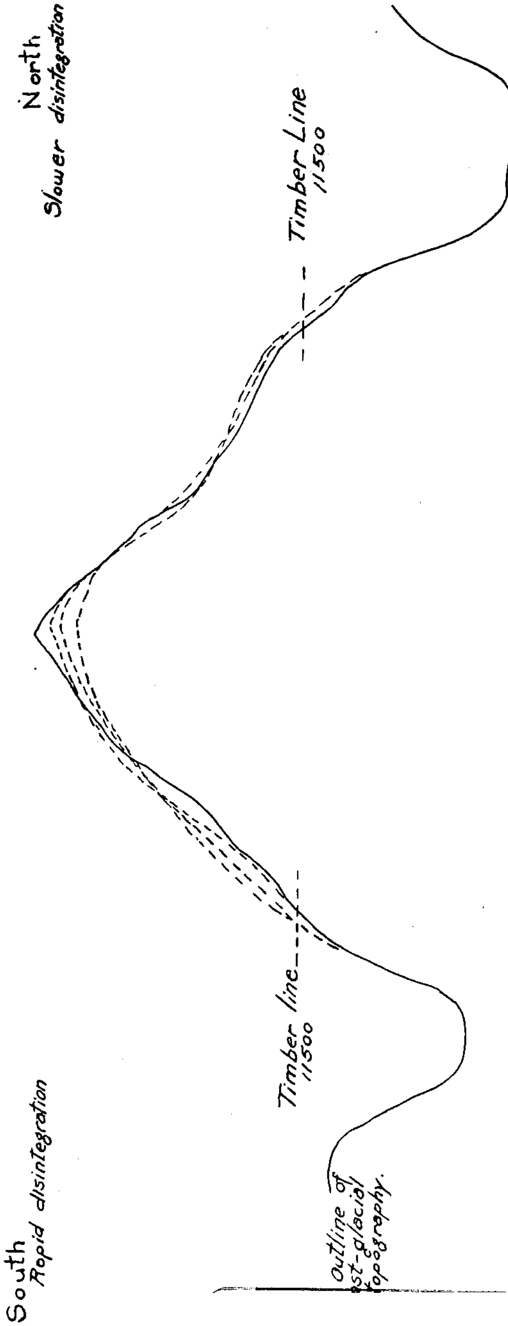

Fig. 3. Sketch showing how flat summits may be developed through the effect of timber line.

Because of these conditions the difference in character of slope on northern and on southern exposures is marked. The south side of Mt. Champion (Figure 4) is typical of the south slopes, the

Fig. 4. Mount Champion as seen from near the head of Lackawanna Gulch. Note the contrast between the southern (left) and northern slopes. Mount Champion mine may be seen at center of photo.

surface being comparatively smooth and grassy, with little or no sliderock. In contrast to this the north side of Mount Casco, nearby, presents a steep, rugged face at whose foot are great streams of sliderock (Figure 5).

Fig. 5. The north side of Mount Casco. The cliff-like face and the streams of coarse talus about the foot are characteristic of the north slopes of the mountains of this region.

The difference is due, no doubt, to the fact that the south side of a mountain in the northern hemisphere —— "is heated more than the north, it is subject to the greater daily range of temperature, and the rock on this side suffers the greater disruption."[10]

EFFECT OF FAULTING ON TOPOGRAPHY

So far as can be determined with any degree of accuracy, faulting has not been important in the development of the present topography. Because of the absence of sedimentary rocks, and of the manner of weathering of the pre-Cambrian metamorphic rocks, faults can be located only with difficulty. Owing to the great amount of glacial erosion it is not possible to decide whether the linear character of the streams is an original character, due to development of their valleys along faults or joints, or whether they were originally more devious and were straightened during the occupancy of their valleys by glaciers.

At the head of Mountain Boy Gulch there is a splendid example of cliffs produced by faulting. A broad, well-defined bench extends in a north-south direction across the head of the gulch. As shown by the diagram, Figure 6, two nearly parallel normal faults have occurred in such manner that a bench of Grizzly Peak rhyolite now

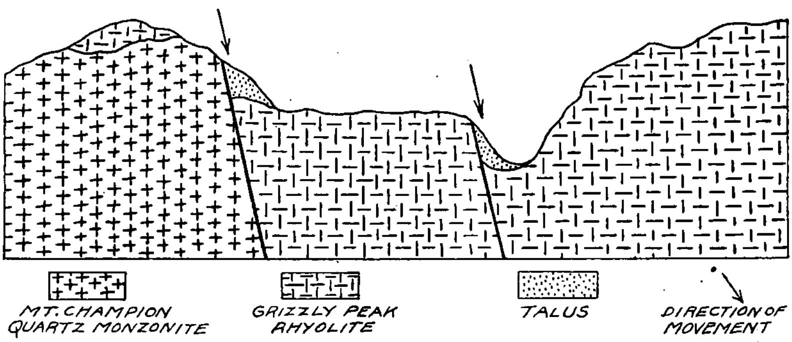

Fig. 6. Diagram showing faulting at the head of Mountain Boy Gulch.

rests at the foot of a cliff of pre-Cambrian granite and gneiss. The stream follows for some distance along the strike of the second and smaller fault. The throw of the greater fault can be determined only approximately, but is not less than 200 feet.

A mile northwest of the faulted area described above, a comparatively recent fault cuts the Grizzly Peak rhyolite in a north-

[10]Chamberlain, T. C., and Salisbury, R. D., Geology, vol. 1, 1906, p. 46.

west-southeast direction, the fault line being a rather well-defined depression which is traceable for somewhat less than a half-mile.

EFFECT OF CHARACTER OF COUNTRY ROCK ON TOPOGRAPHY

The major topographic features appear to have been little affected by the character of the underlying rocks, but the effect on the minor features has been important. In general the topography developed on the massive granitic rocks is more rugged than that where schist and gneiss predominate. The weathering of schistose rocks produces rounded topographic forms which are in rather strong contrast to those produced from massive rocks (Figure 7).

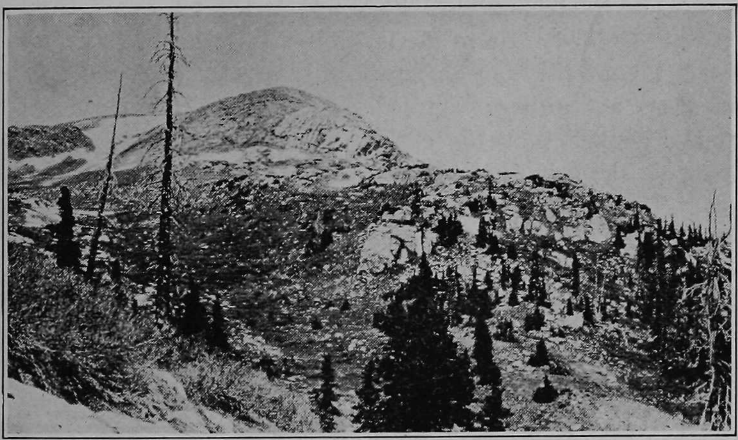

Fig. 7. A small knob of rock near the head of Lake Creek (North Fork). The photograph shows the markedly different topographies developed on quartz monzonite (at the right) and schist (at the left). The contact between the two is near the center of the rounded knob.

Areas of schist which have been injected by quartz monzonite and alaskite often form ridges, due to their greater resistance.

Both the Red Mountain and Grizzly Peak rhyolites, except where ice action at the heads of cirques has produced cliffs, have developed smooth slopes and a less rugged topography than any other formation within the district.

SNOWSLIDES

Snowslides occur frequently during the winter and spring on the steep slopes. Many follow well-defined paths, such as stream courses, and constitute important erosive agents. The most noticeable results, however, are the forming of dams across the streams and the production of extensive meadows by reason of the rapid silting above the obstructions. Through such meadows the stream flows sluggishly in long, flexuous meanders and reverse curves, with occasional ox-bow loops and cut-offs. Several such meadows, the largest nearly a mile in length, break the fall of the North Fork of Lake Creek above Everett.

GLACIAL GEOLOGY

INTRODUCTION

The glacial phenomena of Lake Creek Valley have been so fully described by Capps,[11] Davis[12] and others, that it appears hardly worth while to give more than a brief statement here. The present survey has added little to the information contained in the earlier reports, except that the observations have been extended over certain areas not hitherto studied. Free use will be made of the material contained in the earlier papers, in many cases without specifying the precise source.

EVIDENCES OF GLACIATION

The former occupancy by glaciers of the valley of Lake Creek and those of its tributaries is attested by the following phenomena:

a. The valleys are usually U-shaped in cross-section.

b. The upper portions of the gulches have been expanded by ice action into typical cirques.

c. Bedrock, especially in the main valley, is often polished, striated or grooved.

d. The lower part of Lake Creek Valley contains many lateral and terminal moraines.

e. Tributaries have unconformable relations with the main stream:

   1. Topographic unconformity—hanging valleys.
   2. Incomplete drainage. Lakes, bogs, etc.

f. Serrate divides. Figure 8.

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[11]Capps, S. R., Jr., Bull. U. S. Geol. Survey No. 386, 1909, pp. 54-63.

[12]Davis, W. M., Bull. Mus. Comp. Zool., vol. 49 (Geol. Series, vol. 8, No. 1), 1905, pp. 1-11. Appalachia, vol. 10, 1904, pp. 392-404.

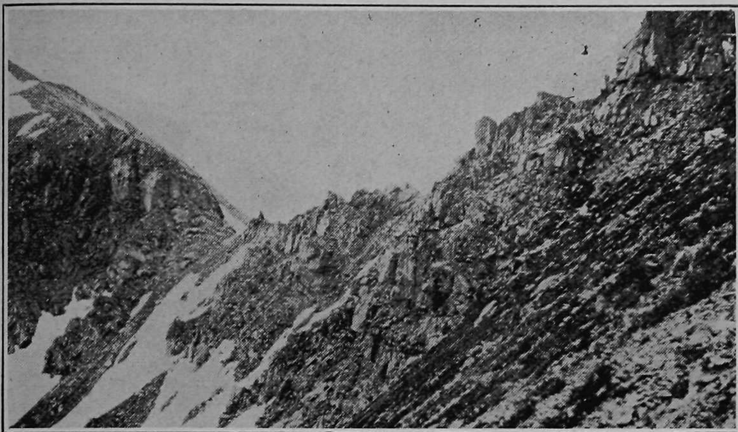

Fig. 8. Serrate divide at the head of the North Fork of Lake Creek. The country rock is pre-Cambrian quartz monzonite.

g. Truncated spurs.

GLACIAL EROSION

The beginning of the Pleistocene or Glacial epoch no doubt found the drainage of the Sawatch Range essentially as it is today. That is, the streams occupied the same valleys, the divides were in nearly the same positions, and the plan of the drainage system essentially that of the present. The topography, however, is vastly different from that of the early Pleistocene.

The youngest rocks of the Twin Lakes district are the Grizzly Peak and Red Mountain rhyolites, which probably are Eocene, or at least Tertiary in age. During the time that ensued between the outflow of the last of these lavas and the formation of the Pleistocene glaciers, the range was subjected to erosion by the usual subaerial agencies, drainage systems were developed and extensive valleys cut. The topography produced was characterized by the following features:

1. The spurs between adjacent tributaries to the main stream trailed toward the main. In other words, the divides between adjacent tributaries became progressively lower in the direction of the main stream and disappeared as the valley was reached.
2. The valleys of both main stream and tributaries were V-shaped.
3. The divides generally were even crested and smooth.

4. The main stream and its tributaries were in adjustment.
5. The valleys of the tributaries were gorge-like, and wider at their mouths than at the heads.

At least once, and probably twice, during the Pleistocene the temperature conditions became such that the annual snowfall exceeded the annual melt in that part of the Sawatch Range which rises above 12,000 feet. This gave rise to glaciers, which were concentrated first in the tributary valleys and later moved downward into the main valley. In this manner the great Lake Creek glacier was formed by accretions from twenty or more gulches which are tributary to it.

The movement of these glaciers, both main and tributaries, resulted in a tremendous amount of erosion. For the bottom of the glacier ice was studded with rigidly held boulders, cobble and sand, which permitted it to act as a huge plane, markedly altering the shapes of the valleys down which it moved. Thus the valleys became broadly U-shaped, were greatly deepened, and the trailing spurs were sharply truncated.

Erosion in the tributary valleys progressed at a rate somewhat less than that which characterized the main valley, where more powerful tools operated. In these tributaries, too, the erosion was greater at the head than at any other point, hence all the gulches were widened and deepened at their upper ends to form the amphitheaters or cirques which are such notable features of the present topography.

The rounded and polished rock surfaces or roches moutonnées, which are so noticeable along the Cutoff Trail at the lower end of Lake Creek, bear many grooves and striae produced by the rocks with which the ice stream was shod. These "sheep backs" nearly always present gently sloping stoss or upstream sides, and more abrupt lee or downstream sides. The glacial polish, "crust," or "case-hardening," which is characteristic of rock surfaces over which glaciers have passed, has been splendidly retained by the massive quartz monzonite porphyry of the lower part of the Lake Creek valley.

The post-glacial topography presents the following characteristics:

1. Spurs between adjacent tributaries are truncated, or faceted.
2. Both main and tributary valleys are broadly U-shaped.
3. The divides are serrate, due to backward cutting by the ice.

4. The main valley and its tributaries are not in adjustment. More intense erosion in the main has brought it to a much greater depth than its tributaries, hence the latter form "hanging valleys." Of this type are Crystal Lake Gulch, La Plata Basin, Lackawanna and Mountain Boy Gulches, and to a less degree all the tributaries of Lake Creek (Figure 10).

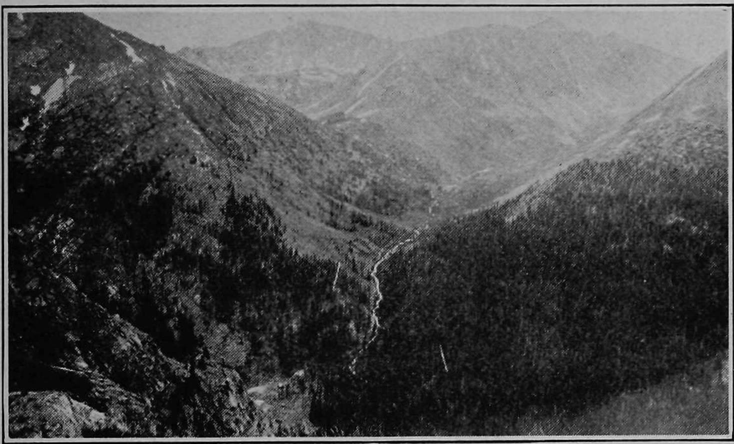

Fig. 9. Lackawanna Gulch. A hanging valley which is also characteristically U-shaped.

5. The tributaries, like the main valley, are broadly U-shaped. Also the heads have been broadened into great amphitheaters or cirques.

Comparison of these characteristics with those of the pre-glacial topography listed above, will give a fair idea of the effects of the glacial erosion.

GLACIAL FILLING

As the Lake Creek glacier moved downward, gouging out its valley, plucking material from the bottom and sides and gathering debris also from its tributaries, it came finally to an elevation at which the average temperature was such that it could no longer exist. For a long period of time the movement of the glacier was approximately equal to its annual wastage by melting at the lower end, and many streams of debris-laden water flowed from the edge of the ice. Of the material carried within the ice, as well as on its surface, much was removed by these streams and deposited at varying distances from the edge as outwash. But a very large part was

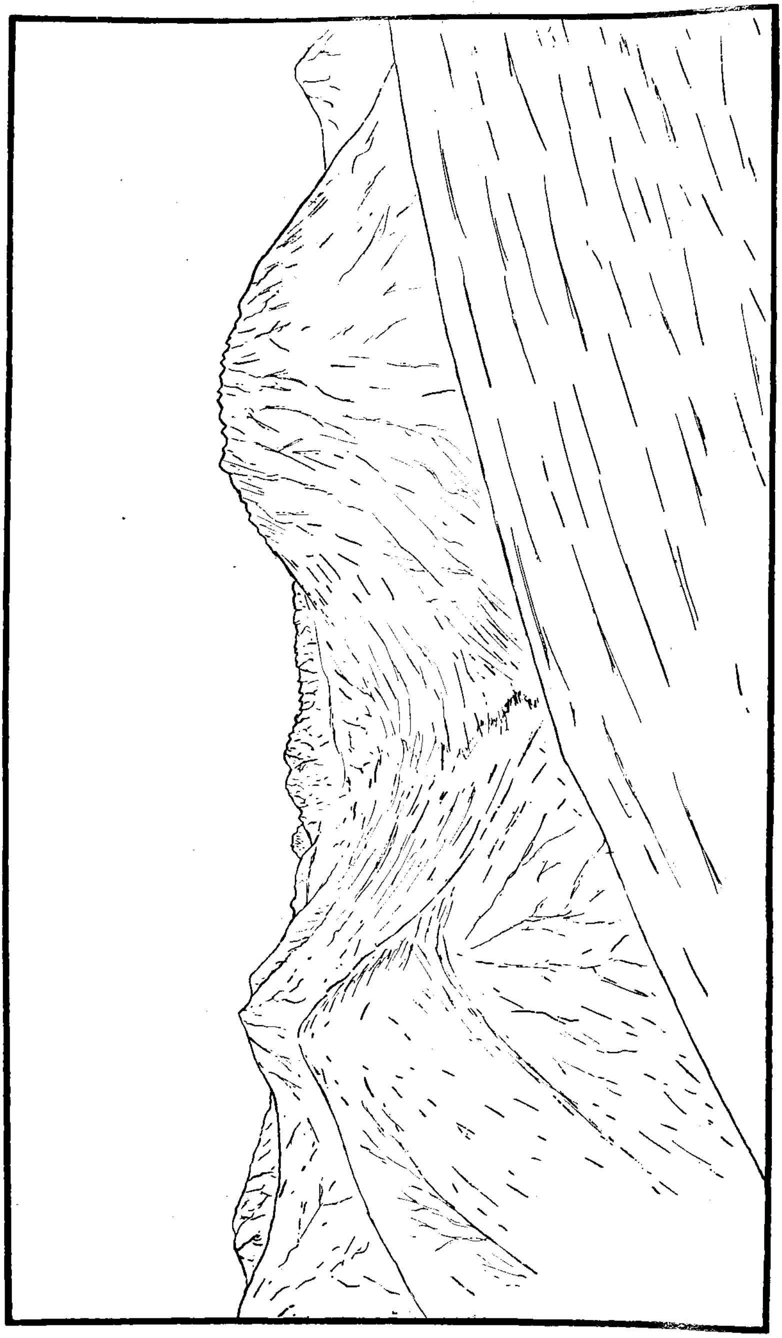

Fig. 10. La Plata Basin from Bull Hill. A hanging valley.

Fig. 11. Sketch showing chief physiographic features of the area surrounding Twin Lakes.

not moved for any considerable distance, and was heaped up about the edge of the glacier to form a terminal moraine. The group of sandy hills lying to the north and east of Lower Twin Lake constitute such a moraine, deposited at the point of greatest extension of the Lake Creek glacier. (See Figure 11.)

After such a period of synchronous melting and movement, there ensued a rapid retreat of the ice, during which no extensive moraine was built. Following this retreat came a second pause, shorter than the first, during which a small terminal moraine, the low strip of land separating the lower and upper lakes, was deposited. After the second pause the glacier retreated rapidly, and, so far as can now be determined, made no other noteworthy stop at any point in the valley above. The conditions which had given rise to glaciation gradually disappeared, and climatic conditions essentially similar to those of today followed.

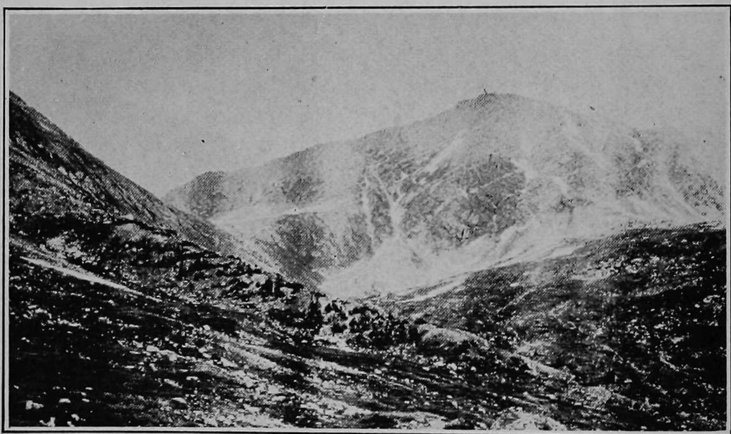

Fig. 12. Medial moraine at the head of the North Fork of Lake Creek. It has been formed at the junction of two small tributary glaciers, one moving from the lower left to lower right, the other from upper right to lower right of the picture. The trees growing on the moraine are about ten feet in height.

The gravel filling of the broad, flat area above the upper lake, as well as that of the various parks and meadows for several miles above, is part of the outwash material resulting from the melting of the glacier. Part, however, is more recent and has been carried down by the streams since the ice vanished. It therefore is true alluvium.

DRAINAGE CHANGES DUE TO GLACIATION

No important changes of drainage occurred as a result of glaciation within the area covered by this report. Just outside its boundaries, however, the Lake Creek glacier produced two changes of considerable interest, viz.: the formation of the Twin Lakes, and the crowding eastward of the Arkansas River during the time of the greatest extension of the ice. These changes are discussed at length in the articles by Westgate,[13] Capps,[14] and Leffingwell,[15] and will not be considered here.

POST-GLACIAL EROSION

The amount of post-glacial erosion has been slight. At the falls of Lake Creek, two miles above the town of Twin Lakes, the stream has cut less than twenty feet below the potholed rock surface, which must once have been in contact with the bottom of the ice. The moraines near Twin Lakes have been little dissected, although their materials are amenable to erosion. At no place is there any evidence that the time which has elapsed since the final retreat of the ice has been other than a very short one, measured geologically.

AGE OF THE GLACIATION

The remarkable freshness of the materials composing the drift, and the slight amount of post-glacial erosion that has taken place, indicate that the glaciation should be assigned to the most recent period of the Pleistocene, the Wisconsin glacial epoch. According to Chamberlin and Salisbury[16] most of the mountain glaciation of the west is referrable to this epoch. Capps[17] has shown that there probably was a period of glaciation much earlier than the one whose effects have been described. But the later invasion removed nearly all evidence of the older epoch, and within the area studied the work of but a single glacier can now be recognized.

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[13]Westgate, L. G., Jour. Geology, vol. 13, 1905, pp. 285-312.
[14]Capps, S. R., Jr., U. S. Geol. Survey Bull. 386, 1909, p. 24.
[15]Capps, S. R., Jr., and Leffingwell, E. D. K., Jour. Geology, vol. 12, 1904, pp. 698-706.
[16]Geology, vol. III, p. 393, 1907.
[17]Capps, S. R., Jr., U. S. Geol. Survey Bull. 386, 1909, p. 61.

CHAPTER III

GENERAL GEOLOGY

INTRODUCTION

The Sawatch Range forms part of the core of the Rocky Mountains, and is composed in great part of the oldest rocks of the region. Within the area covered by the accompanying map no sedimentary rocks occur in place, and the entire district is underlain by highly metamorphosed gneisses and schists which have been intruded by younger plutonic rocks of granitic or monzonitic types. Owing to the character of the country rock little can be inferred regarding the structure, and the ages of the various intrusions are also obscure.

In this chapter an effort is made to outline briefly the important features connected with each of the formations found in the Twin Lakes district, and to trace the geological history with as much certainty as may be possible.

THE ROCKS

THE PRE-CAMBRIAN SERIES

The oldest rocks exposed are designated as pre-Cambrian, the data available concerning them being insufficient to permit of their division into smaller groups. The series includes biotite-sillimanite-schist, biotite schist, talc schist, quartzite, marble, quartz monzonite gneiss, and some minor varieties of metamorphic rocks. Intimately injected into the complex of metamorphic rocks is the Mount Champion quartz monzonite, which probably is of pre-Cambrian age also.

Most of the series consists of rocks which clearly are of metasedimentary origin, and their metamorphism certainly took place before the intrusion of the Mount Champion quartz monzonite, for the latter is not affected. The materials of the schists suggest that the original sediments may have been successions of sandy shales, interspersed by thin lentils of sandstone and impure limestone. Such deposits indicate conditions similar to those far out on the continental shelf at the present time.

TWIN LAKES QUARTZ MONZONITE PORPHYRY

A fresh, coarse-grained monzonite carrying large, euhedral crystals of orthoclase. It is found on both sides of the valley of Lake Creek below Everett and in the vicinity of Twin Lakes. Its age cannot be determined definitely, but is probably late Paleozoic.

QUARTZ HORNBLENDE DIORITE

In the southwestern part of the district, especially in Peek-a-boo and McNassar Gulches, there occurs a medium-grained, greenish-gray diorite. The area exposed is small, and the relations rather obscure, but the available evidence indicates a post-Paleozoic age.

HORNBLENDE DIORITE

A light-colored, almost white, granitic rock carrying small rods of dark hornblende. Covers only a small area on the south end of Middle Mountain and at the head of Sayers Gulch. Age unknown.

PEGMATITES

Coarse-grained dike rocks occurring chiefly in the gneisses and schists. Of various ages and of two distinct types. The quartz-magnetite pegmatite is composed of quartz with varying amounts of crystalline magnetite. The quartz-feldspar type ranges in composition from nearly pure quartz to nearly pure feldspar. All the pegmatites are end products of differentiation in the various magmas.

RED MOUNTAIN RHYOLITE

Occurs in a few small areas in the southwest part of the district, in each case lying on a divide. Petrographically it is a light-colored, siliceous rhyolite containing finely disseminated pyrite, which on weathering produces red iron oxide, the material which is responsible for the brilliant coloring of Red Mountain.

GRIZZLY PEAK RHYOLITE

An extensive flow of rhyolite covers much of the area on both sides of the Continental Divide south of Independence Pass. This is a gray, fine-grained, easily-weathered rock in which are embedded innumerable fragments of gneiss, schist and other older rocks. The color varies from light gray to brown, and the texture from that of rhyolite porphyry to pitchstone. A majority of the included fragments are small, but masses a hundred or more feet in diameter are not uncommon. Age probably Tertiary.

PALEOZOIC(?) LIMESTONE

A mass of crystalline limestone, apparently of Paleozoic age, is found embedded in the upper part of the Grizzly Peak rhyolite at the head of McNassar Gulch. Its area is small, and it has not been mapped, but the presence of such a fragment high up on the Divide has an important bearing on the history of the region.

DIKE ROCKS

Throughout a large part of the district there are found numerous dikes of dense white quartz-porphyry. These are identical in character with those of Aspen, Leadville, Georgetown and other districts of Central Colorado. The dikes probably were intruded during late Cretaceous time.

GEOLOGIC HISTORY OF THE DISTRICT

Owing to the great amount of metamorphism which has taken place since that time, the exact character of the pre-Cambrian rocks may only be surmised. But the shales and sandstones which must have been present to produce the present schists and quartzite indicate that during that period the area now occupied by the Sawatch Mountains was covered, at least intermittently, by an epicontinental sea. To this period the name Algonkian has been assigned. Of the Algonkian history, therefore, little can be said, except that during at least part of the time it was covered by the sea, the conditions varying from near-shore to those which indicate considerable depth and distance from land. Probably the adjacent land masses were low, for there is no evidence of coarse sediments, and but little sandstone (quartzite).

During the latter part of the pre-Cambrian, but long after the Algonkian sediments had been greatly metamorphosed, probably by pressure and heat resulting from deep burial and the stresses set up through orographic movements, the Mount Champion quartz monzonite was intruded into the metamorphic rocks. This intrusion must have been effected by a magma of great fluidity and acting under enormous pressure, for the metamorphic rocks are minutely injected.

On the basis of work in other parts of the Range it may be inferred that following the injection of the schists and gneisses by the Mount Champion magma, there occurred an orogenic movement which lifted the Sawatch region above the sea. This movement marked the close of the Algonkian. According to Emmons[18] the Sawatch Range, or rather the area which it now occupies, has never again been submerged and throughout all subsequent times has remained an island, which he has termed "The Sawatch Island." Not all investigators have agreed with Emmons on this point, and the most recent work indicates that the Sawatch Range was not brought above sea-level until after the close of the Paleozoic era. Hayden[19] believed that at a comparatively modern time the Range had been covered by from 10,000 to 15,000 feet of sedimentary beds. C. A. White[20] decided that the Upper Cretaceous formations, at least, must have extended entirely across the site of the Rocky Mountains. Crawford,[21] as a result of detailed work in the Monarch and Tomichi districts, concluded that "the evidence is strong that a section (of the Sawatch Range) from Monarch Pass northward about twenty miles was not elevated above sea-level until late Paleozoic or post-Paleozoic time." Schuchert[22] has constructed a map showing the paleogeography of North America during the Benton epoch, in which he extends the Cretaceous sea entirely across the site of the present Rocky Mountains. Lee[23] believes that the entire Rocky Mountain region had been subject to erosion for a long period of time preceding the Cretaceous and probably was peneplained before the invasion of the Cretaceous sea, which extended entirely across the site of the present mountains.

The similarity of the formations found on opposite sides of the Sawatch Range, the absence of coarse, clastic sediments about the flanks, the fact that all sedimentary rocks surrounding the mountains dip away from them, and above all, the finding of Paleozoic limestone on or near the crest of the Range, all suggest very strongly that the Sawatch was not elevated above sea-level before the close of the Paleozoic.

At the close of the Paleozoic, and immediately following, there occurred important diastrophic movements throughout most of the Rocky Mountain region. These movements appear to have been closely followed by extensive dioritic and monzonitic intrusions. It

[18]Emmons, S. F., Bull. Geol. Soc. Am., vol. 1, pp. 271-273.
[19]Hayden, F. V., U. S. Geol. and Geog. Survey Terr. 10th Ann. Rept., 1876, p. 48.
[20]White, C. A., U. S. Geol. and Geog. Survey Terr. 12th Ann. Rept., 1883, p. 50.
[21]Crawford, R. D., Colorado Geol. Survey Bull. 4, 1913, p. 103.
[22]Bull. Geol. Soc. Am., vol. 20, 1910, pp. 427-606.
[23]Lee, W. T., U. S. Geol. Survey Prof. Paper 95, 1915, p. 56.

was during this period of activity that the Twin Lakes quartz monzonite porphyry, the quartz hornblende diorite and the quartz diorite must have been intruded, for they correspond closely to rocks of similar age in nearby districts.

It was during the Mesozoic also that the numerous quartz porphyry dikes had their origin. As a result of recent work they are believed to be of late Cretaceous age. The Cretaceous was a time of great orogenic movements in the Cordilleran region, and it is generally held that the Rocky Mountain system had its beginning near the close of the period.

Of the events of the Tertiary there is a more complete record. Throughout the Cordilleran region the Tertiary was a period of great igneous activity, chiefly of a volcanic character, and this activity extended into most of the Sawatch area. The Grizzly Peak rhyolite certainly dates back to this time, and there is reason to believe that the Red Mountain rhyolite also was formed at the same time. The great San Juan volcanoes were active during the Eocene, and the rhyolites of the Twin Lakes district probably are to be assigned roughly to this period. So far as can be determined, the extrusions here were of a quiet type, accompanied by minor faulting.

Since the close of the Tertiary the district has been affected only by very minor diastrophic movements, most of which have consisted of local faulting.

The Pleistocene period witnessed the formation of great ice streams, or glaciers, which were developed near the heads of the valleys tributary to Lake Creek and gradually extended downward into the main valley, eventually merging to form the great Lake Creek glacier. During the occupancy of the valley by this glacier erosion to the amount of over 1,000 feet was accomplished in the main and somewhat less in the tributary valleys. The character of the valleys was greatly changed, the cross-section altered from a V-shape to U-shape, the accumulated debris cleared out, tributaries rendered unconformable with the main valley, and great moraines piled up about the mouth of the Lake Creek canyon.

The post-Pleistocene history has been simple. The ordinary sub-aerial agencies have been engaged in altering the surface of the land, but the time since the disappearance of the ice has been so short that the results have been meager. Little erosion has taken place, even in the morainal material. Large talus streams have been developed on the bare mountain sides, thin mantles of soil have been accumulated in the cirques and on the flat divides, and a few feet of alluvium now covers the glacial material in the valley. Snowslides, by damming the flow of the Lake Creek with their debris, have ponded the stream at many places and aided sedimentation. Many little parks and meadows have been formed in this way.

During the intense glaciation most, if not all, of the oxidized portions of the ore bodies were removed, and the outcrops now reveal sulphide ore within a few feet of the surface. Oxidation has been slight on account of the short time during which it has been operative.

SUMMARY

The geologic history may now be summed briefly:

Pre-Cambrian—Conditions during the Archean unknown. Algonkian sediments indicate that the area was submerged during at least part of this period. At the close, igneous activity became prominent.

Paleozoic—The district was submerged at least part of the era. Near the close some diastrophic movements took place and the region may have been raised above sea-level.

Mesozoic—Record is imperfect. Extensive diastrophic movements near its close resulted in the formation of the Rocky Mountains. Many large monzonitic intrusions. During the latter part of the period the ore bodies probably were formed.

Cenozoic—Extensive volcanic activity throughout central Colorado. Rhyolite flows occurred in the southwestern part of the district, probably during the Eocene. Extensive glaciation during the Pleistocene, which profoundly modified the topography.

CHAPTER IV

PRE-CAMBRIAN, PALEOZOIC AND IGNEOUS ROCKS

PRE-CAMBRIAN SERIES

THE GNEISS-SCHIST COMPLEX

DISTRIBUTION

The heterogeneous series of rocks which is here designated by the term "gneiss-schist complex," constitutes the oldest formation of the district, and all of the igneous rocks have been injected through it. Probably at one time the complex covered the entire area, but subsequent intrusions and extrusions have reduced the exposures chiefly to the bottom and sides of the valleys.

Mount Champion, Deer Mountain, Casco Mountain, Star Mountain and Mount Lackawanna are composed in large part of gneiss and schist, into which there has been injected a quartz monzonite, probably also of pre-Cambrian age. The valley of Lake Creek, from Everett almost to the head of the North Fork, is cut in this series, as are also Halfmoon, Lackawanna and Sayers Gulches. In the vicinity of La Plata Peak the complex predominates.

STRUCTURE

Metamorphism has so far progressed that it is not possible to make other than very general determinations of structure. Planes of schistosity are continuous only for short distances, and correlations, by means other than lithologic similarity are impossible. The character of the schists indicates that they are of sedimentary origin, hence there should be a general parallelism between bedding and schistosity, except where intense injection has occurred. Unfortunately, such injection is common throughout the area, and has been accompanied and followed by extensive minor faulting.

At a time long subsequent to the deposition of the sedimentary rocks which now form the complex, and subsequent also to their metamorphism, the schists were injected by the Mt. Champion quartz monzonite, whose intrusion was so general and whose penetration so intense that it is evident great pressure and high fluidity must have characterized the magma. During the process of intrusion nearly all the original structural features were altered or entirely obliterated.

Van Hise[24] defined schists as "cleavable rocks, the cleavage pieces of which are like one another, and the mineral particles of which are for the most part so large as to be visible to the naked eye." Gneisses he defines as "banded rocks, the bands of which are petrographically unlike one another and consist of interlocking mineral particles." These definitions will apply in this report.

PETROGRAPHY

The complex is very heterogeneous in composition and includes a large number of rock types. Not all of those represented can be described here, but an effort will be made to discuss the more important ones.

Biotite-sillimanite schist—A dark gray to black, foliated, sometimes crenulated rock, usually fine-grained. On weathered surfaces it develops a dull brownish tinge, in places much stained by iron oxide. The laminae are alternately gray and white, the white bands being composed chiefly of quartz. The predominant mineral in the dark bands is biotite. A small amount of muscovite occurs with the biotite. Quartz is a prominent mineral, present as irregular granules throughout the schist, but chiefly collected into the light bands. Sillimanite occurs in large amount as radiating or fibrous bundles of prismatic crystals, elongate in the planes of schistosity, both between the quartz and the biotite and among the blades of biotite.

In many places the schist is contorted, partly as a result of dynamo-metamorphism, but chiefly through the injection of the quartz monzonite.

On Mount Campion and Mount Casco garnets are very abundant in the schists. The crystals are small, usually less than one-fourth inch in diameter, of a reddish brown color and with imperfect faces.

Apparently all the garnets have assumed the form of hexoctahedrons, though the individuals usually are so imperfectly developed that their forms are obscure. According to Van Hise[25] the hexoctahedron should be the most stable possible form of crystal, since stability increases with the symmetry. The presence of gar-

[24] Van Hise, C. R., Mono. U. S. Geol. Survey, vol. 47, p. 779, 1904.
[25] Van Hise, C. R., U. S. Geol. Survey Mono. 47, p. 360, 1904.

nets therefore indicates an extreme of adaptation to the stresses produced by dynamic action.

The garnets vary in color between pink and brown, are nearly always broken and friable, and have a composition which is near almandite. Garnets of this type are characteristic of the mica schists and are developed from sediments which were high in iron and alumina.

Biotite schist—Biotite schist is widely distributed throughout the pre-Cambrian area, but is not found in large masses. It is composed essentially of moderately fine, interlocking biotite leaves having a more or less perfect alignment. The degree of schistosity is variable and increases with the biotite content. The color is black to gray. Associated with the biotite are granular quartz and a small amount of feldspar (species undetermined) as well as considerable amounts of earthy secondary chlorite. Needles of sillimanite are not uncommon.

The biotite schist is closely related to the biotite-sillimanite schist, and probably grades into it. Weathered phases of biotite schist may also be readily mistaken for similar specimens of hornblende schist, as weathering of either rock produces a greenish chlorite schist. Close examination of the latter, however, seldom fails to reveal some trace of the original hornblende crystals.

Talc schist—In a few places, notably on Sheep Mountain, north of Mt. Champion, there are found small areas of talc schist. The exposure on the west end of Sheep Mountain is typical. Fresh fragments are light pea-green in color, have moderately good schistose cleavage, but the planes are irregularly curved. The schist is composed almost entirely of talc and quartz, the latter occurring both as an original and as a secondary mineral. The talc schist can usually be scratched rather easily with the thumb nail. The schist is much fractured, the openings showing no regularity and slight continuity. Slickensides are the rule among the fragments, being readily developed in such soft material. Weathering alters the color of the schist to a light gray and produces great quantities of fine slide-rock.

Because of the large amount of slide-rock the field relations of the talc schist are not always clear, but wherever the relations could be determined it was found to occur as a sheet or dike in the other pre-Cambrian rocks. It probably has been developed through alteration of pre-Cambrian ferromagnesian intrusives.

Quartzite—Lenses of quartzite are of widespread occurrence in the complex, but the lenses are of slight thickness and areal extent. The rock is seen usually in the form of boulders or cobble in the beds of streams flowing through pre-Cambrian areas, hence the field relations cannot be determined.

The quartzite collected is fine-grained, grayish or flesh-colored and very dense. The hand lens reveals only quartz grains accompanied by a small amount of disseminated biotite. Microscopic examination of a quartzite from Sheep Mountain shows that a very complete recrystallization has occurred, the quartz grains being no longer rounded, but having developed irregular, partially interlocking boundaries. In a few crystals there is an irregular central area or core, whose extinction varies noticeably from that of the remainder of the crystal. This core probably represents the original sand grain, which has grown through abstraction of additional silica from the circulating waters. Wavy extinction is not prominent. Near the head of Graham Gulch a very arkosic quartzite was collected, which contains a large amount of kaolin and mica, but most of the specimens seen are comparatively pure. The quartzites undoubtedly are derived from sandstone lenses which were deposited along with the shales and limestones of the pre-Cambrian sediments.

Marble—The only occurrence of marble noted within the district is near the summit of the mountain which stands at the head of the South Fork of Lake Creek, just over the southern boundary of the map. Large fragments are found in the float on the north side of the mountain, but none of the marble was seen in place. Therefore the relation to the pre-Cambrian is somewhat doubtful. However, at Tincup Pass, some sixteen miles to the southeast, highly crystalline marble has been found[26] interbedded with the green schists which Cross considers to be of pre-Cambrian age, and there seems no reason to doubt that the marble occurring on the South Fork bears a similar relation to the schists.

The specimens collected are dark gray, rather coarse in texture, and contain an occasional suggestion of bedding planes. On weathered surfaces may be seen many rounded quartz grains, usually arranged in short lines or lenses. Apparently the original limestone was impure or sandy in character. Accompanying the marble, either as inclusions or attached to it, are masses of a

[26]Cross, Whitman, Proc. Colo. Sci. Soc., January, 1893, pp. 1-10, and quoted by Van Hise and Leith, Bull. U. S. Geol. Survey No. 360, p. 816.

heavy, light green, granular mineral much altered by weathering, but still recognizable as diopside.

Quartz monzonite gneiss—Under this heading are grouped a number of very similar gneisses occurring at various places throughout the area. All have dioritic affinities, but the relative proportions of the alkali and soda-lime feldspars are not constant. Very careful field study, supplemented by examination of a large number of thin sections might divide the group into two or more types, but such refinement is not within the scope of the present report.

The quartz monzonite gneiss occurs interbedded with the pre-Cambrian schists in all parts of the district. It generally is a light to dark gray crystalline rock, of medium texture, and with

Fig. 13. Pre-Cambrian schist injected by the Mount Champion quartz monzonite. Lackawanna Gulch.

definite but not perfect banding. The rock is dense and uniform, and seldom shows any planes of weakness corresponding to the gneissic banding. Gray feldspar and colorless quartz make up the lighter part of the rock, while biotite is the predominant dark mineral.

In thin sections the gneisses are seen to be inequigranular, containing irregular crystals in which inclusions are numerous. Feldspar makes up by far the greater part of the rock. In some sections oligoclase predominates, while in others the feldspar is nearer albite. Orthoclase is present in subordinate amount in nearly all sections. All of the soda-lime feldspars are characterized by very distinct albite twinning; they sometimes occur in very large crystals, but never exhibit distinct crystal outlines. Quartz is present in considerable amount in the form of clear, colorless crystals, irregular or rounded in outline. In one section from Lackawanna Mountain quartz occurs as rounded inclusions in oligoclase crystals.

The black mineral whose segregation into bands has produced the gneissoid character of the rock, is biotite. Under the microscope the linear arrangement is much less distinct than in the hand specimen. The manner in which the biotite fills the interstices between feldspar and quartz crystals indicates rather clearly that it is much later than either, at least in its present arrangement. In an igneous rock biotite is one of the earlier minerals to separate from the magma, hence it tends to develop euhedral outlines. In these gneisses, on the contrary, the biotite occurs in irregular leaves and seldom, if ever, is euhedral.

Although, as suggested before, intensive study of the gneisses may result in a more minute division into several species, there is reason for believing that the various forms are merely phases of the same magma and probably were intruded at about the same time. The reasons for this conclusion may be summed up as follows:

a. All of the forms are found intruded into the same types of schists, and in close proximity to each other.
b. All have dioritic affinities, and contain the same minerals, though in different proportions.
c. All show practically the same degree of metamorphism.

MOUNT CHAMPION QUARTZ MONZONITE

Distribution—The gneisses and schists of the pre-Cambrian, wherever exposed, have been intimately injected by an almost entirely unmetamorphosed quartz monzonite. In general this intrusion has taken the form of sheets, varying in thickness from a few inches up to many hundred feet. The texture is uniform and the composition shows no greater range than would be expected in an intrusive mass of such wide distribution.

The quartz monzonite is typically exposed on Mt. Champion, and has for that reason been given the name Mt. Champion quartz monzonite, in order to distinguish it from other later quartz monzonites. Its greatest areal extent is in the vicinity of Mt. Champion, Lackawanna Mountain and Independence Pass, but it is found associated with the gneiss-schist complex wherever the latter occurs.

Structure—The quartz monzonite occurs as sheets interbedded with the gneiss and schist, and therefore is structurally similar to the older rocks. Because of extensive faulting, much of which no doubt was contemporaneous with the intrusion, the sheets tend to cut across the planes of schistosity to a very considerable extent. These excursions are, however, at very slight angles with the schistosity, and the attitude of the quartz monzonite masses rarely approaches that of a dike.

Dynamo-metamorphism has been relatively unimportant since this intrusion took place, and the quartz monzonite has been affected only locally. The gneissoid character which may be seen at a few places, notably on Mounts Casco and Lackawanna, seems to have been original rather than the result of metamorphism.

Inclusions of schist and gneiss are numerous in many parts of the quartz monzonite, and suggest that stoping[27] may have played an important part in the process of intrusion. Assimilation appears to have been slight, for most of the included fragments have not been greatly altered in outline. One noticeable effect of the schist blocks has been the concentration along their boundaries of bands of coarse biotite. For a short distance from the boundaries the schist has been baked to such an extent that the narrow zone is now much more resistant to weathering than is the central portion of the block.

Megascopic description—The Mt. Champion quartz monzonite is a light gray, crystalline rock of medium texture. It breaks readily and uniformly, but shows a marked tendency to pulverize on breaking, due, probably, to the weakening effect of the large amount of feldspar. With the hand lens the rock is seen to be composed principally of coarse crystals of feldspar, averaging about 5 mm. in diameter, though many are two or more times that size. All show good cleavage. Carlsbad twinning is commonly seen, and striated plagioclase crystals are not uncommon. Quartz occurs as small colorless crystals, rather uniformly distributed among those of feldspar. Coarse black biotite occurs throughout the rock.

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[27]Daly, R. A., Am. Jour. Sci., vol. 26, p. 19, 1908. (Also several earlier papers.)

Microscopic description—The general texture of the rock is holocrystalline, inequigranular. Microcline, plagioclase, orthoclase, quartz and biotite are the important minerals. Magnetite and apatite are accessories.

Microcline is the most prominent mineral constituent and occurs in large irregular crystals, most of which exhibit splendid gridiron twinning. This gridiron effect is the most conspicuous feature of the sections.

Orthoclase is present in small amount as anhedral crystals, of much smaller size than those of microcline. The two potash feldspars appear to bear no definite relation to one another.

Albite is the most important plagioclase present. and is associated with a smaller amount of *oligoclase.* No other members of the plagioclase group were recognized. Albite twinning is general and very distinct. Crystals are allotriomorphic, show no definite orientation and average about half as large as those of microcline.

Quartz occurs to the amount of nearly 12%, as large corroded anhedrons. The extinction is uniform and there is no evidence of either undulatory extinction or strain bands. A few small, rounded anhedrons occur as inclusions in microcline and plagioclase crystals.

Biotite is distributed throughout the rock as irregular masses or shreds. The color of most basal sections is a rich brown, but a few show a greenish tinge, the change probably being due to alteration.[28] The axial angle is variable, but is always sufficient to produce noticeable separation of the hyperbolae. Pleochroism is marked.

Magnetite is distributed sparsely through the rock in irregular, corroded grains. It is usually associated with biotite and in many cases bears small rounded inclusions of apatite.

A few small corroded anhedrons of *apatite* appear as inclusions in the magnetite.

The mineral composition, as determined by the Rosiwal method, is shown in the table below. On account of the coarse texture of the rock the individual crystals are relatively large as compared to an entire section, and the results of measurements by

[28]Iddings, J. P., Rock Minerals, p. 424.

this method are less accurate than in the case of rocks of fine texture:

Quartz	11.82
Orthoclase	9.87
Microcline	40.98
Plagioclases	22.58
Biotite	10.19
Magnetite	2.38
Iron Oxide	2.06
Apatite	.12
	100.00

Age—The gneiss-schist complex of the Twin Lakes district seems to be practically equivalent to the Idaho Springs formation described by Ball[29] in the Georgetown district, and by him referred simply to the pre-Cambrian. Similar rocks have been described from the Monarch-Tomichi[30] district, Aspen[31] district, Crested Butte,[32] Breckenridge[33] and other neighboring localities. At many of these places known Upper Cambrian sediments rest unconformably on the ancient schists and gneisses, and fix the minimum age as early Cambrian. It is generally assumed that the Algonkian marked the beginning of the dominance of sedimentation and that the formations composed chiefly of sedimentary or meta-sedimentary rocks are not older than Algonkian. For although sediments do occur in the Archean they are commonly subordinate.

The Mt. Champion quartz monzonite intruded into the schists and gneiss probably is the equivalent of the pre-Saratogan or even pre-Cambrian intrusions mentioned by Cross[34] as occurring widely in the pre-Cambrian of Central Colorado. These rocks are metamorphosed very slightly, if at all, hence must be considered as very much younger than the highly metamorphosed rocks which they cut. Cross[35] says:

Wherever any considerable area of Archean gneisses and schists in Colorado has been closely examined it has been found to be penetrated by intrusive igneous rocks, often in a very intricate interlacing of different varieties. The rocks here referred to are either unmetamorphosed

[29]Ball, S. H., U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.
[30]Crawford, R. D., Colorado Geol. Survey, Bulletin No. 4, p. 18, 1913.
[31]Spurr, J. E., U. S. Geol. Survey Mono. 31, pp. 1-8, 1898.
[32]Cross, Whitman, U. S. Geol. Survey, Geol. Atlas Folio No. 9.
[33]Ransome, F. L., U. S. Geol. Survey Prof. Paper 75, p. 25, 1911.
[34]Cross, Whitman, U. S. Geol. Survey Bull. 360, p. 826, 1909.
[35]Cross, Whitman, U. S. Geol. Survey Bull. 360, p. 826, 1909.

or but locally affected. They do not penetrate the early Paleozoic sediments, where the latter are preserved, and hence must be considered as pre-Saratogan, if not strictly pre-Cambrian. At least part of these massive rocks must be considered as of Algonkian or post-Algonkian age.

Among these intrusives granites are by far the most common, but syenite, monzonite, diorite and gabbroic rocks are known as occurring in large bodies.

The preponderance of evidence appears to be in favor of a late Algonkian or early Cambrian age for the Mt. Champion intrusion. The evidence, however, is indirect, and therefore inconclusive.

It seems best to consider the gneiss-schist complex as being early Algonkian, because of its predominantly sedimentary character, and its complete metamorphism. Concerning the age of the ancient metamorphic rocks of the Sawatch Range, Van Hise and Leith[36] state:

> The presence of limestone and quartzite in the pre-Cambrian schists of the Sawatch and adjacent valleys suggests the Algonkian age of this part of the series, but the granites and other gneisses and schists may be of the same or different ages. The best that can be done is to refer the entire complex to the pre-Cambrian.

PROBABLE MESOZOIC INTRUSIVES

TWIN LAKES QUARTZ MONZONITE PORPHYRY

Distribution—The valley of Lake Creek from Everett to Twin Lakes is cut through a characteristic light gray, coarse-grained, porphyritic rock, which, in this report, has been given the name Twin Lakes quartz monzonite porphyry. The glacially polished valley walls and the surfaces of the *roches moutonnées* of the lower part of the valley exhibit the porphyrytic character especially well.

This monzonite porphyry forms the floor of Lake Creek valley and extends far up the walls and up the tributary gulches on either side, being overlain irregularly by the older gneisses and schists of the pre-Cambrian complex. The monzonite-schist contact gradually approaches the valley level until, just above Everett, it passes beneath the stream bed. In general the schists dip away from the monzonite mass at angles of 40° to 60°.

Chiefly because of the striking appearance of the porphyry it has attracted the attention of every geologist who has visited

[36] U. S. Geol. Survey Bull. 360, p. 829, 1909.

the region. Thus Wheeler[37] speaks of it as a porphyritic syenite. Hayden[38] called it a granite porphyry and noted that the phenocrysts are orthoclase. Among the miners the term "corn granite" is occasionally applied to this rock.

Megascopic Character—The monzonite is uniformly of a light grayish or bluish color, the texture of the ground mass is moderately coarse, and the large, euhedral orthoclase phenocrysts are scattered thickly throughout. These phenocrysts have well defined crystal outlines, are usually symmetrical, often very large, and a majority of them are twinned according to the Carlsbad law. Zonal structure is apparent on the weathered surfaces of many of the phenocrysts. The porphyritic character of the rock is especially noticeable on the smoothly polished glaciated surfaces near the lower end of the valley.

The phenocrysts, whose form and optical properties prove them to be orthoclase, are variable in size and proportions, some being short and thick, others elongate. One crystal, which was collected near the Gordon mine, measured 3.75x7x3 inches, and many others nearly as large may be found. The twinning is visible in nearly all of the large crystals and in many of the smaller ones. Zonal structure of the phenocrysts is less common, but may be seen on many glaciated surfaces. On some of the polished knobs, notably near the bridge across Lake Creek, 2 miles above Twin Lakes, differential weathering has caused the phenocrysts to stand out in strong relief, the feldspar apparently being more resistant than the matrix. Inclusions of biotite and of quartz occur in many of the large phenocrysts.

It is noteworthy that the large phenocrysts occur even within a few feet of the contact with adjacent rocks. The largest crystals, however, are found at some distance from the boundaries.

Two distinct types of segregation are found, one of which probably is the result of mechanical processes. In the mechanical type large numbers of the large orthoclase phenocrysts have been brought together and form the major portion of the rock for a space of several feet. Such a segregation may have been caused by settling of the newly formed phenocrysts in the still liquid magma, and their localization into these large groups.

Segregations of the second type are numerous and widely distributed, but are of small size. They are produced by the accumu

[37] U. S. Geog. and Geol. Surveys W. 100th Mer., vol. III, p. 440.
[38] U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept., 1873, p. 241.

lation of the dark ferro-magnesian minerals, particularly biotite, into more or less rounded masses, usually less than 6 inches in diameter, but sometimes exceeding one foot. In these segregations but little of the other rock-making minerals remains, the composition being nearly pure biotite.

Because of the uniformity of the rock the jointing is very definite and perfect. The most prominent set of joints has a strike of N. 20° E., but there are many subordinate systems intersecting the major joints at angles approaching 90°. Near the Falls of Lake Creek, about 2 miles above the town of Twin Lakes, the joint planes are nearly parallel and only a few feet apart. This arrangement results in the formation of huge flat slabs.

Microscopic Character—In thin sections the texture is seen to be coarsely holocrystalline, inequigranular, with large phenocrysts of orthoclase.

Orthoclase is an important constituent, occurring in large, subhedral crystals, many of which show Carlsbad twinning. Zonal structure is sometimes present. The large crystals carry inclusions, usually small and anhedral, of hornblende, apatite and quartz, all of which are corroded.

A few scattered crystals of *microcline* are found, all of which show good gridiron twinning. The amount of microcline is very much less than that of orthoclase and the plagioclases, but the mineral seems to be of constant occurrence. The crystals are irregular in shape and size.

Oligoclase is a prominent mineral, occurring in large anhedral crystals, and in amount about equal to that of orthoclase in the groundmass. Some zonal structure, simulating that of orthoclase, renders it easily confused with that mineral, from which, however, it may be readily distinguished by its higher index of refraction, as well as by other less simple tests. Twinning is obscure. Many small inclusions of magnetite are scattered through the crystals.

Albite is found in a few small crystals, showing good twinning, with sharp and distinct lamellae.

Quartz occurs as irregular anhedral grains, some of which show corrosion. Wavy extinction is prominent. The amount of quartz present, about 12 to 15 per cent., is subordinate to that of the feldspars. The most prominent femic mineral present is *biotite*, which constitutes about 2 to 3 per cent. of the rock. It occurs as brown, pleochroic masses and shreds with no definite crystal outlines.

A few small, greenish, pleochroic crystals of *hornblende* are found, but the total amount is negligible.

Occasional small, rounded anhedrons of *apatite* occur, generally as inclusions in the masses of magnetite. The apatite is clear or only slightly cloudy, colorless, has high relief and shows many irregular checks or cracks. Evidently it was the first mineral which crystallized from the magma, and was immediately followed by the magnetite.

Numerous masses of *magnetite*, some of considerable size and usually without crystal outline, occur throughout the rock. In most cases the peripheral portion of the magnetite mass is altered to a brownish material which probably is *limonite*.

Field Relations—As mentioned previously, the quartz monzonite porphyry extends beneath the upturned pre-Cambrian schists along all contacts which can be studied. The eastern boundary of the monzonite mass lies somewhere within the broad valley of the Arkansas River, and the relations there can only be

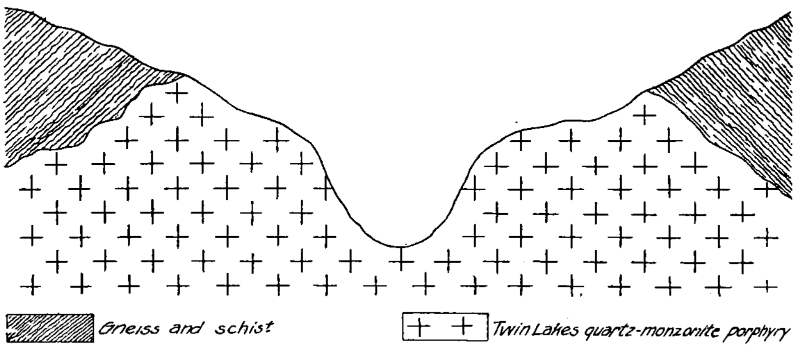

Fig. 14. North-south section across Lake Creek showing general relations of the schist and the Twin Lakes quartz monzonite.

conjectured. The sketch (Figure 14), shows the general relation of the monzonite mass to the pre-Cambrian Complex. If it were possible to replace the material removed during the excavation of Lake Creek valley, there is little doubt that the schists would extend entirely across that area and form a continuous roof over the body of monzonite porphyry. Such a relationship indicates clearly that the monzonite is an intrusion of the batholithic type. This is further confirmed by the fact of its coarsely porphyritic texture, and by the presence of occasional arms or stringers extending into the schist from the main mass. But on the whole, these arms are much less numerous than would be expected.

Age—Evidence bearing on the age of this intrusion is rather meager, and the time at which it reached its present position can be determined only approximately. Its remarkable freshness indicates that it cannot be very ancient, and its porphyritic character proves that it must have been intruded long before the uplift which has resulted in the present extensive dissection of the region.

At many other places in the state quartz monzonite porphyry is cut by quartz-porphyry dikes of post-Carboniferous and probably late Cretaceous age.[39] It is reasonable to suppose that this occurrence may be of the same age.

As the only other rocks of the district which are cut by the monzonite porphyry are of pre-Cambrian age, it is obvious that the direct evidence gives little information.

Some assistance is gained by comparison with rocks of nearby districts. In the Monarch district Crawford has described monzonite intrusions which are of post-Carboniferous age. Emmons[40] describes monzonitic intrusions in the Leadville district which he considers to be Mesozoic in age. It is not improbable that the Twin Lakes batholith originated at the time of the important Mesozoic orogenic movements in the Rocky Mountain region, and that it is closely related to other monzonitic intrusions in neighboring districts. It has been tentatively assigned to the Mesozoic.

QUARTZ-HORNBLENDE DIORITE

Distribution—In McNassar and Peek-a-boo Gulches and near Grizzly Mountain are several small areas of diorite whose relations are rather obscure, both on account of the limited exposures and the fact that it usually is found to be covered by flows of rhyolite.

Megascopic description—The diorite is a uniform, greenish-gray crystalline rock, occurring as a coarse breccia. The indi-

[39] Ball, S. H., U. S. Geol. Survey, Prof. Paper 63, p. 71, 1908. Emmons, S. F., U. S. Geol. Survey Mono. 12, pp. 74-89, 1886. Spurr, J. E., U. S. Geol. Survey Mono. 31, p. 53, 1898.

[40] Colorado Geol. Survey Bull. 4, pp. 138-160, 1913. U. S. Geol. Survey Mono. 12, p. 74, 1886.

vidual fragments of the breccia range in size from a fraction of an inch to many feet in greatest dimension.

Quartz and feldspar are the dominant light-colored minerals. Hornblende is the chief dark mineral, and is present in sufficient amount to produce the greenish hue of the rock. When the surface is examined with a lens, striated feldspar crystals are seen to be numerous.

Microscopic description—The texture is holocrystalline, inequigranular, the hornblende crystals being much larger than those of the other minerals. Crystals of all minerals are irregular in shape and show no crystal outlines.

The most prominent of the plagioclases is *labradorite,* which occurs in coarse, anhedral crystals, usually exhibiting sharp albite twinning. No pericline twinning is seen. With the labradorite are smaller amounts of untwinned *anorthite* and a little *andesine.* Small masses of *kaolin* are found scattered through all of the plagioclase crystals, and are especially numerous along the boundaries.

Hornblende occurs as large, anhedral, greenish crystals, showing excellent cleavage, especially in basal sections. Pleochroism is marked, the changes being from gray-green to brown. A few crystals show twinning. Short, rounded rods of apatite occur in small amount as inclusions in the hornblende.

Quartz is present in subordinate amount as irregular anhedral crystals. No corrosion has occurred.

A small amount of *magnetite* is found, both alone and associated with hornblende. The grains usually are small. *Apatite* inclusions are numerous.

The rock is here given the name quartz-hornblende diorite,[41] as it seems most closely allied to that type. It is, however, very closely related to Iddings' quartz gabbro, except in its greater amount of quartz.

Age—The diorite is found to cut the pre-Cambrian complex, and is therefore younger than this particular pre-Cambrian formation. It is in turn cut by the alaskite pegmatite dikes also, but their age is not known. Because of its similarity to other dioritic intrusions of the Crested Butte[42] and Aspen[43] areas whose age is

[41] Iddings, J. P., Igneous Rocks, vol. I, p. 358 ;vol. II, p. 63, 1909.
[42] Cross, Whitman, U. S. Geol. Survey Geol. Atlas Folio 9, p. 4.
[43] Spurr, J. E., U. S. Geol. Survey Mono. 31, p. 53, 1898.

known, a similar age has been tentatively assumed. The dioritic laccoliths of the Crested Butte quadrangle cut both the Montana and Laramie strata, and are therefore post-Early Cretaceous. In the Aspen district the diorite is known to be at least post-Carboniferous. On Teocalli Mountain, Gunnison County, according to Cross,[44] stocks of diorite are found cutting Carboniferous strata. Crawford[45] has described a quartz diorite from the Monarch district which he believes to be post-Carboniferous, and possibly Tertiary.

The Grizzly Mountain rhyolite lies on an eroded surface of the diorite at many places (Figure 15), hence a long interval must have elapsed between the periods of vulcanism which produced them. For the diorite is coarse in texture and must have been intruded beneath a very great thickness of rocks, which have since been removed by erosion. If the rhyolite is of Tertiary age, then the diorite is much older.

The best that can be done is to consider the diorite to be of post-Carboniferous age.

HORNBLENDE DIORITE

Distribution—On the south side of Middle Mountain and again at the head of Sayers Gulch, there are found areas of a light-colored, granitic rock, which is readily distinguished from any other formation in the district. Its distinctive features are the light, almost white color of the groundmass and the presence of small rods of hornblende which are scattered thickly through the rock.

Description—The hornblende diorite is of medium texture, light color, holocrystalline and composed chiefly of quartz and feldspar. The prevailing whitish groundmass is sprinkled thickly with small dark-colored rods of hornblende, the contrast between the light and dark minerals being such that the rock resembles a porphyry. Some leaves of biotite are present, but the mineral is not abundant. So far as can be seen with a lens, the various minerals are but slightly decomposed and the rock, as a whole, appears very fresh.

In thin sections the chief minerals are seen to be feldspars and quartz, with a very subordinate amount of hornblende. Some biotite and apatite are present. The texture is holocrystalline and

[44] Cross, Whitman, U. S. Geol. Survey Bull. 150, p. 242, 1898.
[45] Colorado Geol. Survey Bull. 4, pp. 130-134, 1913.

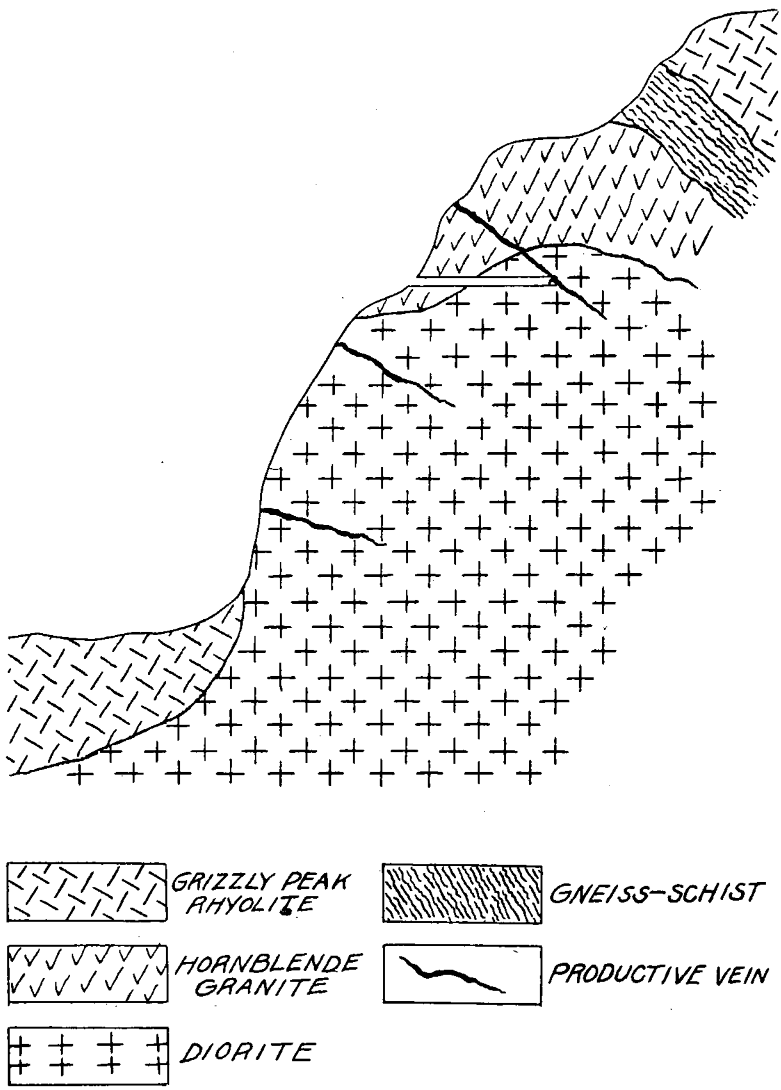

Fig. 15. Geologic cross section through Middle Mountain.

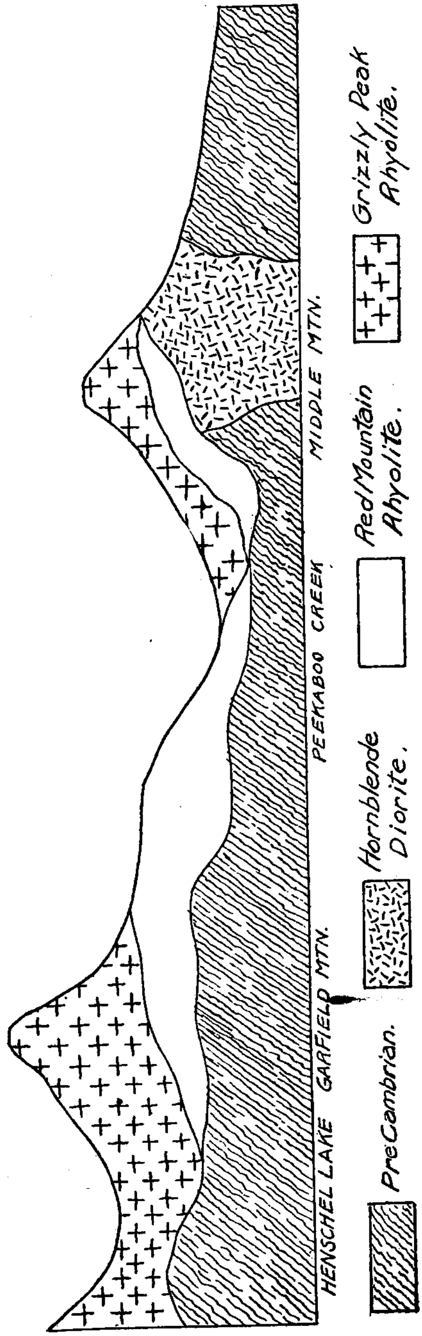

Fig. 15a. Northwest-Southeast section across Peekaboo Creek, at Henschel Lake, showing probable geologic conditions.

the pattern generally uniform and allotriomorphic. A few quartz crystals are corroded.

Oligoclase and *albite* together constitute 65% to 70% of the rock. Oligoclase is the more abundant, is usually twinned, though much less sharply than albite, and in some crystals has a zonal structure. A few small crystals of *orthoclase* are present.

Hornblende, in rather short, greenish, pleochroic, generally euhedral crystals, is present to the amount of 4 to 5%. The cleavage is good and little alteration is noticeable.

Quartz is subordinate in amount only to the feldspars, and occurs in anhedral crystals of medium size. Extinction is normal. Many of the crystals are corroded.

Biotite occurs sparingly as brown, pleochroic leaves and shreds. *Apatite* is found as small, scattered anhedrons in the hornblende. A few very small prisms of *zircon* are found, apparently as an original constituent.

Structural Relations—Owing to the limited areas and the unsatisfactory character of the outcrops, little is known concerning the relation of the hornblende diorite to the other rocks of the district. It cuts the pre-Cambrian gneisses and schists and the Mount Champion quartz monzonite, and is overlain by the Grizzly Peak rhyolite. Along Peek-a-boo Creek it is in contact also with the quartz-hornblende diorite, but little of the actual contact can be seen. None of the quartz porphyry dikes are known to cut either diorite.

Age—Beyond the fact that the hornblende diorite is younger than the youngest pre-Cambrian formation, and older than the Grizzly Peak rhyolite, nothing can be said regarding its age. It probably is related to the quartz-hornblende diorite which is found nearby. If it be assumed that the two rocks are derived from the same magma, then according to the normal rule for plutonic intrusions,[46] the hornblende diorite, being less basic, should be the younger.

PEGMATITES

Quartz-magnetite pegmatite—Stringers of pegmatite, consisting wholly of quartz and magnetite, are of common occurrence in the vicinity of Mounts Champion and Casco. The injection of the

[46]Harker, Alfred, The Natural History of Igneous Rocks, p. 116, 1909.

schists of Mount Casco by this material has been so intense that the magnetic declination there has been measurably affected.

The pegmatite occurs as dikes or stringers interbedded with or cutting the pre-Cambrian gneisses and schists. The bodies are nearly always small, although one which outcrops on the Lone Star property on Mount Champion is ten to fifteen feet in width. As none of the pegmatite is found in the younger formations, it may safely be assumed that it is very little younger than the gneisses and schists themselves. The proximity to the apophyses of the Mt. Champion quartz monzonite renders it possible that the pegmatite is a differentiation product of the monzonitic magma.

Quartz is the predominant mineral, but is accompanied by a small amount of orthoclase. Magnetite is distributed through the quartz in irregular masses, usually without definite form, but occasionally having the crystal outlines developed. The magnetic property of the specimens collected is not great.

Biotite is present in some dikes and absent in others, but may be expected whenever the magnetite is present in large amount. It occurs in foliae of moderate size.

Quartz-feldspar pegmatite—Pegmatites of this type differ from the one previously described, chiefly in the absence of magnetite. The types are not absolutely distinct, and may well have come from the same magma, for they occur in close proximity at many places.

The composition of the quartz feldspar type ranges from nearly pure quartz to nearly pure feldspar, the average composition being much nearer the quartz end of the series. Some of the intermediate dikes are practically coarse-grained alaskites or aplites, and are much more numerous than either extreme. A typical quartzose dike is found along the crest of Mount Casco, where it has been exposed in a number of prospect holes, evidently having been mistaken for a vein. It is made up almost wholly of coarse white quartz, with only an occasional small feldspar crystal.

Along the divide between Lake Creek and the South Fork of the Frying Pan (north edge of the map) is a broad dike which in places is composed in large part of feldspar. The crystallization is very coarse, and well-formed orthoclase crystals, ten to twelve inches in length, have been found. There is a tendency toward concentration of certain minerals into restricted areas within the dike, so that the composition changes abruptly from place to place. In areas of muscovite concentration, plates of clear mica, three to four inches in diameter, are found. Black tourmaline, apatite and fluorite are found occasionally, but are not common. Red garnets were seen in a single specimen.

The intermediate type, as has been stated, approximates an alaskite or aplite in composition. In this case the term aplite appears preferable, for the rock is composed entirely of quartz, feldspar and muscovite, thus constituting a white granite. In the broad cirque at the head of the North Fork of Lake Creek, and also in Independence Pass, these aplite dikes are especially conspicuous. The texture is medium to coarse, or locally graphic, and the color nearly white. Quartz and flesh-colored (weathering to white) feldspar, with a subordinate amount of rather coarse muscovite, are recognizable in the hand specimen. In thin section the feldspar is found to be chiefly orthoclase, but with some oligoclase and microcline.

Origin of the Pegmatites.—Pirsson[47] describes the formation of pegmatites as follows:

> When a body of molten magma has come to rest in the chamber it is destined to thenceforth occupy as a solidified rock mass, cooling and eventually crystallization begin. During this period of crystallization the volatile substances dissolved in the magma and previously contained under pressure, such as fluorine, boric acid, carbon dioxide and especially and chiefly water, which have been already described as mineralisers, are gradually excluded, except in so far as they may take part in the chemical composition of some of the minerals.

These vapors and fluids which have been "squeezed out of" the solidifying magma are forced outward and upward to zones of lower pressure, and when they crystallize in fissures of the overlying rocks are known as pegmatite dikes.

Owing to their high temperature, and to the presence in them of various mineralizers, especially water, the heated vapors are very active chemically. This activity manifests itself in extensive solution of the rocks through which the vapors pass, thus materially altering their character before they reach a zone in which crystallization can occur. Thus in the Georgetown district, as pointed out by Spurr,[48] a very similar pegmatite has had its feldspar molecules partially changed to muscovite by addition of alumina from the alumina-rich schists through which it passes. The same ex-

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[47] Pirsson, L. V., Rocks and Rock Minerals, pp. 174, 175, 1913.
[48] Spurr, J. E., U. S. Geol. Survey Prof. Paper 63, p. 64, 1908.

planation may hold for much of the muscovite in the dikes at the head of Lake Creek.

The magnetite appears to have been an original constituent of the magma, inasmuch as it is a constant accessory mineral in the Mount Champion quartz monzonite, from which the pegmatite magma is thought to have been differentiated.

TERTIARY EXTRUSIVE ROCKS

RED MOUNTAIN RHYOLITE

Distribution—The name "Red Mountain rhyolite" has been given because of the typical development of the rock on the mountain of that name.

The areal extent of the rhyolite is small, yet it is one of the most conspicuous formations of the district, its brilliant red color rendering it visible for many miles. The only considerable masses within the area covered by the map are those of Red Mountain, at the head of Peek-a-boo Creek, and of another eminence which rises to the east of Sayers Gulch. The latter will be referred to as "East Red Mountain," as no distinctive local designation seems ever to have been given it.

From the crest of the divide on Red Mountain many similar red patches may be seen capping the mountains and hills to the westward. No doubt they are composed of the same rock as the areas here described.

Description—Two rather distinct phases of the rhyolite have been observed. The first is the normal, or massive phase, the second a brecciated form. The latter, if its origin be considered, may be further divided into two general divisions, volcanic breccia,[49] and talus breccia. These distinctions are purely physical, the petrographic character of each being identical.

In the typical exposures on Red Mountain (Fig. 16) the rhyolite is a light gray to white, fine grained, quartzose rock, originally massive, but now broken and brecciated by weathering processes. The texture is crystalline, and the most prominent mineral, megascopically, is quartz. Under a hand lens the quartz is seen to be associated with a soft, opaque, white mineral which has the appearance of clouded feldspar. Minute specks of pyrite as well as cavities from which the pyrite has been removed, are abundant.

[49]Norton, W. H., A Classification of Breccias. Jour. Geology, vol. XXV, p. 168, 1917.

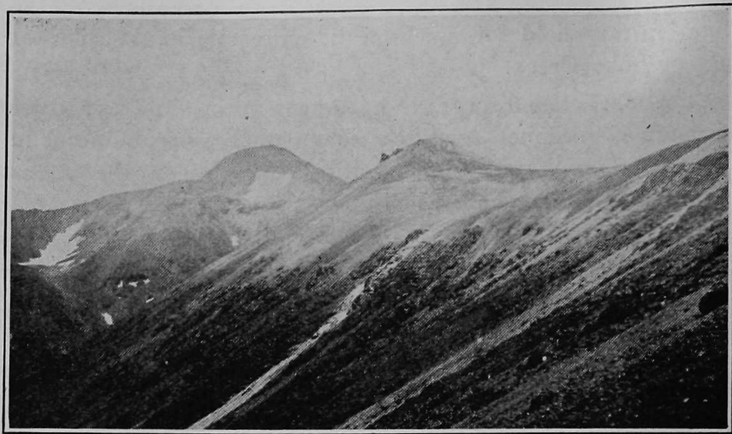

Fig. 16. East side of Red Mountain. The smoothly rounded crest is the result of weathering of the Red Mountain rhyolite. The entire crest is bright red in color.

Weathering of the rock proceeds actively, especially through the agency of the mechanical processes which are predominant at altitudes where it is found. The talus produced is generally fine, and forms broad, smooth ridges, and long, graceful fans. At a little distance the ridges have somewhat the aspect of dunes, and in fact the material of which they are composed is but slightly coarser than dune sand. It is possible that the high winds that prevail on the peaks may have been influential in developing the present contours.

The color of the weathered material ranges from white to deep maroon, through the intermediate shades of yellow, cream and brown. On the broad top of Red Mountain the deep red material forms a layer 3 to 4 inches in depth; below this lies a bed of from 6 to 12 inches of yellowish fragments, together with interstitial yellow clay. The color becomes lighter with depth, until finally the white, unweathered rhyolite is reached, seldom more than four feet from the surface.

Unquestionably the red color is the result of the oxidation of ferrous salts contained in the rhyolite, and as suggested by Peale,[50] these must have originated from the finely disseminated pyrite. The red color is produced by a thin coating, 1/32 of an inch or less in thickness, which covers exposed parts of the surface fragments. Its composition approximates that of hematite, Fe_2O_3. Absence of water in the composition is rather difficult to explain satisfactorily,

[50]U. S. Geol. and Geog. Survey of Colorado, 7th Ann. Rept., 1873, p. 211.

as oxidation by atmospheric oxygen of a ferrous to a ferric salt supposes the interaction of a molecule of water:

$$4FeSO_4+O_2+3H_2O=2Fe_2O_3.3H_2O+4SO_3$$

(limonite)

forming a brown mineral, limonite. It seems probable that the formation of the lower oxide, turgite, and the anhydrous oxide, hematite, may have been determined by atmospheric conditions which were unfavorable to hydration. The areas of red color occur at altitudes of 12,500 to 13,500 feet above sea level, and at such heights low temperatures are the rule. Temperatures as high as 32° F. (0°C.) are reached only during the middle of the day in summer, and not at all during the remainder of the year. Furthermore, the atmospheric pressure decreases greatly above sea level (30 in. mercury) until at 12,500 feet the pressure is but 19 inches. The amount of moisture contained in the air when saturated at 0° C. (sea level pressure) is 4.8 grams per cubic meter, corresponding to a vapor pressure of 4.57 mm. of mercury. Such an arid condition may not only retard hydration, but even hasten dehydration.

Microscopic Character—The readiness with which the rhyolite succumbs to the agents of mechanical weathering has resulted in extensive fracturing throughout the entire body. Through the openings thus produced meteoric waters have percolated and have greatly altered the rock. The alteration is so complete that strictly fresh specimens for petrographic study cannot be obtained. The description given here is therefore less complete than could be desired.

The texture is holocrystalline, mediophyric, with seriate intersertal fabric. The crystals are very irregular in shape and size.

Quartz makes up the greater portion of the rock, feldspar being present in small amount only. The quartz occurs as irregular, clear, colorless crystals. Extinction is normal.

The feldspar is much altered and only a few small crystals of orthoclase could be identified. Presumably the remainder of the feldspar is of the same kind. Considerable kaolin occurs in the form of short, imperfectly crystallized rods clustered around the walls of small irregular openings. These openings appear to be cavities from which feldspar crystals have been weathered.

Few pyrite crystals can be seen in the sections, since the matrix is too soft to retain them during the grinding process.

Those remaining exhibit no definite crystal forms, and the matrix is so greatly altered that the age of the pyrite is indeterminate.

The rock appears to be a siliceous rhyolite. It has been given the distinguishing name "Red Mountain" because of its typical development on the peak of that name.

Breccia Phase—Generally associated with the normal phase of the rhyolite there occurs a poorly cemented breccia composed of fragments of the normal rock. The position, character and relations of the various exposures of the breccia are essentially uniform, and the mode of origin can readily be determined. The breccias are in nearly all instances covered by Grizzly Peak rhyolite, to whose protection they owe their preservation.

Briefly stated, the mode of origin of the breccia is as follows: The Red Mountain rhyolite has been, and is, a great talus former. It weathers mechanically in such rapid manner that cliffs are never formed, and gentle, talus-covered slopes are produced. A talus stream permits rough sorting by gravitation, assisted somewhat by pluvial waters. Therefore at any given place in such a talus stream there would be a rough accordance in size of fragments.

Many such piles of angular debris, the interstices between the coarser blocks being loosely filled by lithologically identical material brought down from the surface of the talus field by the wind, water, or gravity, were formed previous to the extrusion of the Grizzly Peak rhyolite. The later lava flowed out over the surface, filled the valleys, overwhelmed all except the highest hills, and buried the talus slopes beneath hundreds of feet of rock. Subsequent to the burial of the talus, and the cooling of the supercumbent lava, ground water deposited a small amount of siliceous cement in the interstices of the breccia. Along with the silica the waters carried a small amount of pyrite, and in some places a little galena.

Age—The Red Mountain rhyolite is certainly older than the Grizzly Peak rhyolite, and appears to be younger than the quartz porphyry dikes. Ball[51] has shown that the dikes probably are of late Cretaceous age, so the rhyolite certainly is post-Cretaceous. Since the age of the Grizzly Peak flow is not definitely known, little more can be said. Probably both may well be referred to the great period of general volcanic activity which began with the close of the

[51]U. S. Geol. Survey Prof. Paper 63, p. 71, 1908.

Cretaceous and continued through the early part of the Tertiary, reaching a maximum during the Eocene.[52]

GRIZZLY PEAK RHYOLITE

Distribution—The Grizzly Peak rhyolite has been so termed because of its typical development near Grizzly Peak. It is found only in the area south of Hunter Pass and west of Everett, within which boundaries it is the predominant rock. It is not continuous, but is found to cap practically every ridge within the area thus outlined and seldom is found near the bottoms of the deeper valleys. Its irregular distribution can be best understood by reference to the geological map.

The rhyolite is most typically developed in the vicinity of Grizzly Peak and the heads of Graham and Mountain Boy Gulches, where also it attains its maximum thickness. It is also the predominant rock along the south side of the valley of Roaring Fork for several miles to the westward of Hunter or Independence Pass.

A single small patch of this rhyolite is found well down in the valley of Lake Creek, almost due west of the Miller mine. Here the area exposed is about 50 to 100 feet in width and 500 feet in length.

Megascopic description—The rhyolite is a fine-grained, light-gray to buff rock, weathering to various shades of brown. It is much fractured and broken and produces smooth slopes of fine talus, which weather eventually to a coarse, sandy soil. Weathering occurs rapidly along the numerous joints, with the result that steep cliffs never develop except at the heads of cirques where the glaciation has been intense. (Figures 17, 18.)

The rock contains many phenocrysts of clear quartz and flesh-colored feldspar, averaging from one to three millimeters in diameter. The quartz phenocrysts are smaller than those of orthoclase and their outlines usually show corrosion, even in the hand specimen. Some parts of the rhyolite carry only feldspar, others only quartz phenocrysts.

Small crystals of biotite are uniformly distributed throughout the rock, although they may be absent locally. The biotite leaves are small, but are nearly always euhedral in outline.

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[52]Anthracite-Crested Butte, Spanish Peaks, Walsenburg, Telluride and La Plata folios of the U. S. Geol. Survey.

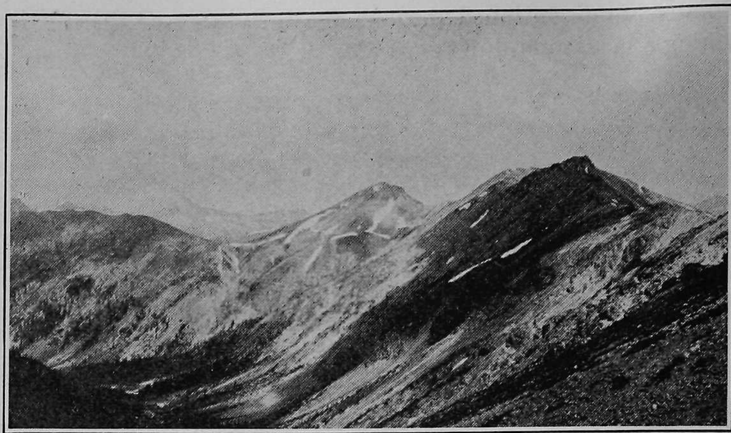

Fig. 17. Looking along the Continental Divide from the corner of Lake, Chaffee and Pitkin Counties. All of the mountains in the foreground are composed of Grizzly Peak rhyolite.

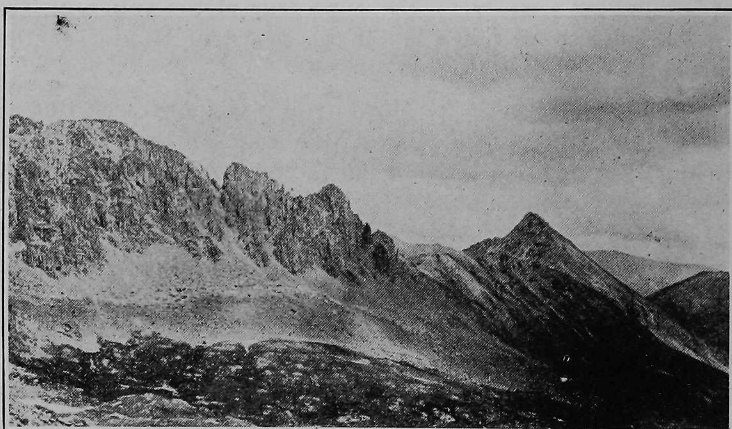

Fig. 18. East side of Middle Mountain near the Bwlchgoch mine. Showing roughly columnar weathering in the Grizzly Peak rhyolite.

A number of different phases of this rock have been observed. While these are not wholly separated from each other and not always readily distinguished, it may be convenient to describe them under a number of heads, as follows:

(a) Light-colored rhyolite.
(b) Medium-colored rhyolite.
(c) Dark-colored rhyolite.
(d) Pitchstone.
(e) Contact facies.
(f) Breccia.

It is not always possible, in examining a given specimen of the rhyolite, to decide whether it should be classed as light, medium or dark. Except for the differences in shade, due to slight variations in texture and composition, the three varieties are alike. But in the face of a steep cliff at the head of Grizzly Gulch the three phases may be seen superimposed one above the other. The lowermost layer, which lies on the pre-Cambrian, is dark brown in color, of fine texture, even glassy in places, is regularly jointed and weathers into characteristic towers, owing to the fact that the vertical joints are more prominent than the horizontal. The thickness of this dark layer is 200 to 300 feet.

Immediately above the dark phase, and separated from it by a generally sharp, though irregular line, is a buff-colored band from 100 to 200 feet thick, showing horizontal ridges due to differential weathering of bands of harder and softer material. These bands simulate bedding planes, but probably are due to flowage lines in the lava.

Capping the series is a bed of still lighter, almost white, porphyritic rhyolite which weathers unequally, but exhibits much less marked flowage lines than the underlying phase.

As nearly as can be determined, the amount of the basic minerals is greatest in the dark phase and least in the light upper phase.

At a few localities, notably at the head of Mountain Boy Gulch, a pitchstone phase occurs along the contact with the underlying massive pre-Cambrian monzonite. The rock is glassy, of a dark-brown color, and is dotted thickly with lighter spherulites.

The contacts at other places are marked by a platy or columnar structure which extends through a distance of five feet or less. Plates twelve inches square and three-eighths inch thick are not uncommon in such places. Most of the fracture pieces are, however, less plate-like, and the general tendency is toward a small scale columnar structure. A limited area of true columnar structure is found at the base of the rhyolite at the head of Peek-a-boo Gulch.

The most striking feature of the flow undoubtedly is the presence in it of vast numbers of small, angular fragments of older rocks. So numerous are these fragments that in places the rock may almost be termed a breccia. In fact, Peale[53] has discussed it as a volcanic breccia. However, it is clear that the inclusions constitute

[53] U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept., 1873, pp. 240-242.

by far the smaller part of the entire rock, and the nature of the matrix should be given first consideration in assigning a name. The inclusions are distributed with remarkable uniformity throughout much of the rhyolite. They are lacking in the small outlier near the Miller mine and in the area immediately south of Independence Pass, but the number increases gradually from Graham Gulch southward. There appears to be no relation between number of inclusions and color of the rhyolite.

Schist inclusions constitute about half of the total number, with granite (includes all granitic rocks) next in importance. Gneiss and rhyolite are less common. All schist fragments, and nearly all of the others, are angular, and give no indication of having been partially absorbed. The size of the fragments is variable, but the vast majority of them are less than two inches in greatest dimension. Larger masses, several feet in diameter, are not uncommon, and Hayden[54] has described one, outside the district covered by this survey, which is of mapable proportions. A few of the inclusions, especially those of the granitic rocks, are somewhat rounded, but this is the exception.

It appears that the number of inclusions diminishes with distance from the contact with the older rocks, although this cannot be stated as a hard-and-fast rule. There certainly is a relation between the size of the inclusions and the distance from the older rocks, the larger ones being found nearest the contact. The decrease in size is very rapid within the first 50 to 100 feet, while thereafter it is so gradual as to be unnoticed.

On many of the broad, flat divides which have been developed by erosion of the rhyolite, the surface is so covered with fragments of schist, gneiss, and other older rocks, that one may be led to believe that the underlying rock is pre-Cambrian. Closer investigation, however, shows that weathering has removed practically all of the rhyolite matrix from the breccia, while the more resistant inclusions have remained unaffected.

Microscopic Character—The Grizzly Peak rhyolite is a holocrystalline, fine-grained rock whose accurate determination microscopically is not easy. Locally, the texture is glassy, while all specimens studied exhibit strongly the ropy structure which is characteristic of most rhyolite flows. Phenocrysts of quartz and orthoclase are numerous, the quartz having the more distinct crystal outlines.

[54]U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept., 1873, p. 241.

The groundmass is composed almost wholly of quartz and orthoclase. Its texture varies from fine granular to glassy and almost always exhibits a ropy texture which corresponds closely to the "axiolitic texture" described by Iddings[55] in the lavas of Yellowstone National Park. In this texture spherulitic crystallization has taken place along the axes of collapsed threads of pumice. The more or less distinct lines which characterize this ropy structure are sinuous and irregular, often folded and crumpled upon themselves. The lines always bend around the phenocrysts. Usually also the texture is noticeably finer adjacent to the quartz and feldspar crystals, and spherulites are occasionally found arranged about them in several concentric layers.

Quartz is the predominant mineral in most sections, especially in the groundmass. It occurs as clear, euhedral or corroded crystals as well as in angular fragments, which undoubtedly were derived from volcanic ash which fell upon the surface of the flow and was incorporated in it.

Orthoclase is, next to quartz, the most important mineral in the rock. It is generally subordinate to the quartz in the groundmass as well as among the phenocrysts. Crystal outlines are obscure or absent and absorption has occurred in most of those whose outlines bear any resemblance to those of crystals. Twinning is not common, but a few of the larger phenocrysts are seen to be twinned according to the Carlsbad law. Zonal structure is rare.

A thin section of a specimen from the small rhyolite mass just west of the Miller mine contains a few small fragments of *plagioclase*. The crystals are small and much decomposed, but most closely resemble albite.

Biotite occurs in small amount as leaves or shreds scattered through the sections. Many euhedral phenocrysts are present, especially in the specimens from Sunset Mountain.

Age and Genetic Relations—The Grizzly Peak rhyolite is the youngest igneous rock in the district. It overlies, or contains inclusions of, every other formation with the possible exception of the Red Mountain rhyolite. No other igneous rocks of later age having cut it, and no sediments being in contact with it, the age of the rhyolite cannot be determined with certainty. From field evidence alone the best estimate possible is that it is younger than the quartz porphyry dikes and younger also than the Red Mountain rhyolite.

[55]Iddings, J. P., Igneous Rocks, vol. I, p. 333.

Comparison with the extrusive rocks of nearby districts seems to shed some light on the problem of age. The Tertiary was a period of great volcanic activity in the Rocky Mountain region, and it was during this time that the lavas and tuffs of the San Juan province were extruded.[56] Rhyolites, tuffs, and breccias whose origin has been traced to this so-called San Juan period of igneous activity, have been found in the Monarch District,[57] which is but a few miles south of the farthest point to which the Grizzly Peak flow was traced. The rhyolite of the Crested Butte[58] quadrangle dates from the same period.

Hence in the absence of conclusive evidence, it seems fairly safe to consider the Grizzly Peak rhyolite to be of Tertiary (Eocene?) age, and part of the great series of volcanics which followed, or were part of the San Juan eruptions.

Origin of the Inclusions—Two processes were active in the collection of the great number of inclusions which occur in the rhyolite. In the first case, the violence with which the eruption occurred undoubtedly shattered great areas of the surrounding rock, and the fragments thus produced were incorporated into the outflowing lava. The second process became active as the viscous rhyolite spread out over the land surface, where it cemented talus heaps, alluvium and boulders, some of which, through the movements within the flow, may have been raised to considerable distances from the bottom. It appears improbable that by the latter means any very large fragments could have been transported for more than short distances, hence the larger inclusions may be considered as being distinctly local in origin.

Talus slopes are generally homogeneous, the degree of homogeneity depending of course on the nature of the cliff from which the fragments emanated. Thus a talus heap formed at the base of a wall of diorite would, if cemented by a lava flow, have the appearance of a diorite breccia, and be very properly designated as such, provided the diorite comprised the major part of the resulting rock. Such a process must have produced the various breccias which mark the contact zone of the Grizzly Peak rhyolite.

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[56] U. S. Geol. Survey Geol. Atlas. Needle Mountains, Ouray, Telluride, Silverton and Engineer Mountain Folios.
[57] Crawford, R. D., Colorado Geol. Survey Bull. 4, p. 75, 1913.
[58] U. S. Geol. Survey Folio 9.

LATE CRETACEOUS DIKE ROCKS

QUARTZ PORPHYRY DIKES

Distribution—The Twin Lakes district lies within the "Porphyry Belt," as outlined by Ball,[59] and its dikes are readily comparable to the intrusive porphyries of neighboring districts. This belt of porphyries extends in a southwesterly direction from Boulder to Aspen and Crested Butte, broadening from about ten miles at its northern end to nearly seventy-five miles at the southern extremity. Included within these boundaries are many of the most important mining districts of Colorado. The relationship between the belt of porphyries and the mineral belt clearly is more than a coincidence.

In the Twin Lakes area the quartz porphyry dikes are found cutting the pre-Cambrian rock, the alaskite dikes and the Twin Lakes quartz monzonite porphyry. They are most prominent in the vicinity of Mount Champion, about the head of the North Fork of Lake Creek, and in the monzonite porphyry area between Everett and Twin Lakes. The dikes are more numerous and larger on Mount Champion than elsewhere. Locally the dikes are known as "porphyry," "block porphyry" or "phonolite."

Megascopic description—The quartz porphyry, as seen in the dikes, is a fine-grained, tough, compact gray or gray-green rock, breaking with a characteristic block fracture (Figure 19). The joint planes are so close together and so regular in direction that it is difficult to find specimens suitable for trimming. The production of plane faces along the fractures is noteworthy. True conchoidal fracture is never seen, and irregular fracturing such as is common in other fine-grained rocks is rare. Blocks having plane, or nearly plane faces twelve inches to eighteen inches square, have been found whose thickness, measured perpendicular to such faces is not more than four to six inches. The average block more nearly approaches a quadrate form.

The jointing appears to be governed by the wall rocks, the two most prominent sets being perpendicular to and parallel with the boundaries. The high silica content of the porphyry indicates that the viscosity of the molten magma was great, hence stringers might be expected to accompany only the larger dikes, while lines of flowage parallel to the walls, and due to slight movements in the

[59] U. S. Geol. Survey Prof. Paper 63, pp. 67-71, 1908.

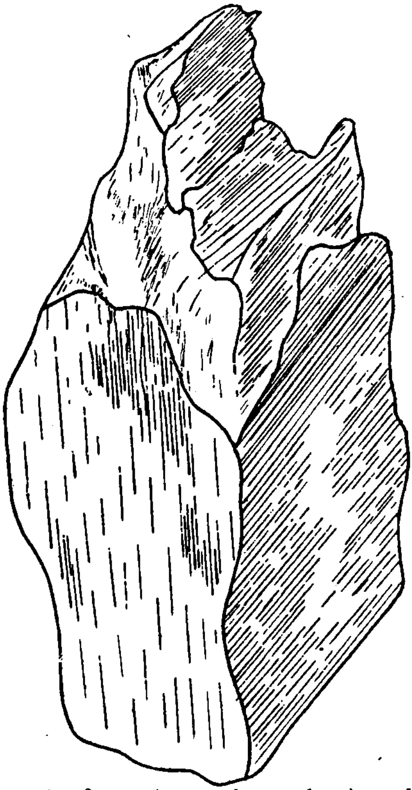

Fig. 19. Fragment of quartz porphyry showing characteristic block fracture.

still plastic lava, should be of common occurrence. Field study bears out both these suppositions. Most of the dikes are small, although many are continuous for several hundred yards, and branching is seldom seen.

Weathered surfaces of the porphyry are, as a rule, somewhat glazed, and stained by iron oxide to a yellow or buff color. The iron oxide appears to be derived from the surrounding rocks. Pits in the surface, formed by removal by weathering of the feldspar phenocrysts, are abundant. Dendritic markings of manganese dioxide occur along many of the minor joint planes.

Alteration of the porphyry, as studied in the Gordon, Fidelity and Mount Champion mines, produces a soft, chalky mass, which retains the old joints to a marked degree. On removal from the mine and drying, the rock becomes much harder. It is not clear whether the kaolin and sericite to which the feldspar has been altered, are the result of the action of meteoric or magmatic waters. The alteration, however, has been very complete.

In the larger dikes the texture at the center is measurably coarser than along the boundaries, where the rock may be almost glassy. Flowage lines usually are present in the glassy parts, indicating that the magma was highly viscous at the time of its intrusion. Mineralizers, if present at all, were in small amount.

The groundmass of the rock is always microcrystalline, with prominent small phenocrysts of quartz, muscovite and orthoclase. The muscovite crystals usually are euhedral and the crystal outlines distinct. The quartz phenocrysts, on the other hand, are rounded by corrosion.

Microscopic Character—As seen in thin section, the rock is holocrystalline, allotriomorphic, and is composed of a microcrystalline groundmass of quartz and orthoclase in which are imbedded phenocrysts of quartz, orthoclase and muscovite. The quartz phenocrysts are much corroded. Those of orthoclase are more numerous and less corroded than the quartz crystals, and many of them show Carlsbad twinning. The muscovite crystals show little or no corrosion.

Petrographically the porphyry is a rhyolite, of the type usually termed a quartz porphyry.

Relations—Quartz porphyry dikes occur in the pre-Cambrian rocks, and in the Twin Lakes quartz monzonite porphyry. They are clearly younger than the Grizzly Peak rhyolite, for the latter contains many inclusions of quartz porphyry.

In the areas of metamorphic rocks the strike of the dikes is approximately that of the schistosity, but in general the dikes dip at somewhat greater angles. Their attitude therefore is midway between that of dikes and of sheets.

Hand specimens of the quartz porphyry of the Twin Lakes district have been compared with specimens from Aspen, Leadville and Georgetown, and all found to be practically identical. Spurr[60] discusses the Aspen rock as a quartz porphyry. Cross[61] describes the "white porphyry" of Leadville as a quartz porphyry. Spurr[62] describes the dikes of the Georgetown quadrangle under the term alaskite, but the rock appears to be similar to the others.

[60] U. S. Geol. Survey Mono. 31, pp. 49-53, 1898.
[61] U. S. Geol. Survey Mono. 12, p. 77, 1886.
[62] Spurr, J. E., U. S. Geol. Survey Prof. Paper 63, p. 77, 1908.

The work of Spurr[63] in the Aspen district, Emmons in the Leadville[64] and Tenmile[65] districts, and Fenneman[66] and Ball[67] in the Boulder district, has shown that the dikes probably are of late Cretaceous age.

In the correlation of the various porphyries the presence in them of muscovite phenocrysts is, as pointed out by Spurr,[68] of very great importance. Muscovite is not common in volcanic rocks, and its uniform appearance in all of the porphyry dikes mentioned is strong evidence of their close relationship.

SEDIMENTARY ROCKS

PALEOZOIC LIMESTONE

Very near the crest of the Continental Divide at the head of McNassar Gulch is a mass of limestone 100 to 150 feet across, included in the Grizzly Peak rhyolite. It is to be seen imbedded in the rock of the steep western wall of the gulch, where it stands out clearly as an almost white area in the prevailing dark gray of the rhyolite.

Near the edges of the inclusion the calcium carbonate of the limestone has been partly altered to wollastonite, but at a short distance from the boundaries the composition is still calcareous. Recrystallization has occurred throughout the mass, but is not quite complete, for not all remains of life have been obliterated. Great numbers of crinoid stems remain and are easily recognizable.

The rock may be described briefly as a coarsely crystalline, blue-gray marble containing crinoid stems as the only identifiable remains of life.

Owing to the fact that the marble outcrops on an almost perpendicular face it was not possible to investigate it as fully as might be desired. Its relation to the surrounding rock is very difficult to determine for this reason. The great amount of talus which lies beneath the cliff, however, affords ample material for study of the petrographic character.

Age—The absence of identifiable fossils renders any statement as to the age of the limestones rather hazardous. Crinoid stems afford no definite clue except to indicate that it is Paleozoic. Pirsson

[63]Mono. U. S. Geol. Survey No. 31, pp. 49-53, 1898.
[64]Mono. U. S. Geol. Survey No. 12, p. 294, 1886.
[65]U. S. Geol. Survey Tenmile Folio, 1898.
[66]Fenneman, N. M., U. S. Geol. Survey Bull. 265, pp. 35-40, 1905.
[67]Ball, S. H., U. S. Geol. Survey Prof. Paper 63, p. 71, 1908.
[68]U. S. Geol. Survey Prof. Paper 63, p. 132, 1908.

and Schuchert state[69] that: "Crinids (crinoids) appeared early in the Ordovician, but are not common fossils until the Silurian, when they are plentiful, and remain so until the close of the Paleozoic."

It is possible that this may be a remnant of the Leadville limestone (Lower Carboniferous) which is found at Leadville, Aspen and near Crested Butte. The presence of the crinoid stems, the bluish color and the fact that the Leadville limestone practically surrounds the Twin Lakes district, suggest such a relation, but there is little real evidence to support the hypothesis.

Relation of the Limestone to the Geologic History—The maps of the Hayden Survey showed no sedimentary rocks in the Twin Lakes district, nor for a distance of twenty miles on either side. The area thus bounded by sediments, but itself uncovered by them, corresponds roughly to that of the Sawatch Range, and has been termed by Emmons[70] the Sawatch Island, on the assumption that it had remained above sea-level ever since pre-Cambrian time.

Later investigators, on circumstantial evidence alone, have denied the existence of such a Paleozoic-Mesozoic island.[71] The evidence is strong that the late Cretaceous sea entirely covered the site of the present Rocky Mountain Range, and must therefore have covered the Sawatch Island. This subject is well summarized in the paper by Lee, cited above. Evidence of submergence during the Paleozoic era is less conclusive, however, and requires further proof.

It would seem that the presence of the block of Paleozoic limestone near the middle of this supposed island, and twenty miles from the nearest limestone in place, is conclusive evidence that the original distribution of the limestone was much greater than at present. It is scarcely conceivable that a block of such large size (150 to 200 feet in diameter) could have been conveyed a distance of twenty miles, either by ejection from a volcanic vent or as an inclusion in the rhyolite flow. The more plausible explanation is that it was picked up by the flow from some nearby outcrop, which outcrop is now either covered by the flow, or has been removed by erosion.

[69]Pirsson, L. V., and Schuchert, C., Textbook of Geology, 1915, p. 658.
[70]Emmons, S. F., Bull. Geol. Soc. Am., vol. I, p. 271.
[71]Schuchert, C., Paleogeography of North America. Bull. Geol. Soc. Am., vol 20, 1910. Paleogeographic map of N. America during the Benton epoch. Lee, Willis T., U. S. Geol. Survey Prof. Paper 95, p. 56, 1915.

CHAPTER V

ECONOMIC GEOLOGY

THE ORE DEPOSITS

GENERAL FEATURES

All known ore deposits of the district, excepting placer deposits mentioned below, are in veins, differing from one another chiefly in size and extent of mineralization. The gangue in every case is quartz, the valuable metal native gold, and the associate minerals pyrite and galena. The gold appears to be always directly associated with the pyrite. All of the veins show areas of crustification, and in some of them this structure is characteristic. Openings are not large, but usually are lined with relatively coarse quartz crystals. The pyrite is of medium or fine grain, occurring either filling the interstices between quartz prisms or as intergrowths with the quartz. Small cubes of pyrite embedded in the gangue also are characteristic.

The size of any given vein will be found to vary greatly on both strike and dip. It is not uncommon to find veins which decrease from widths of eight to ten feet to mere stringers within distances of a hundred feet. So far as can be determined, there is no invariable relation between character of country rock and width or continuity of the veins. Generally, however, the large veins lie in monzonites, diorites or other massive rock, or in parts of the gneiss-schist complex which have been intensely injected by monzonite. Schists are not favorable to the development of large veins.

A few veins in the Grizzly Peak and Red Mountain rhyolites differ markedly from the normal type in the character of minerals carried. A vein in Grizzly Peak rhyolite near the head of Mountain Boy Gulch carries rather coarse galena in a gangue of barite. In the same rock near Three Cabins occur quartz veins containing veinlets of molybdenite. Inasmuch as the barite and molybdenite are found only in that part of the district which has been covered by the two rhyolite flows, there is reason for believing that the two are in some way related.

The positions of all the veins approached the vertical rather closely. Considerable post-mineral faulting has occurred, most of which is of a minor character, and has caused but slight offsetting of the ore bodies. There is little evidence of any re-opening of the solution channels, and none of a second period of mineralization. The age of the post-mineral faulting probably is to be correlated with the late Tertiary or post-Tertiary faulting which is seen at the head of Mountain Boy Gulch. These later faults are unmineralized.

Inclusions of country rock, always much altered and occasionally pyritiferous, occur in all of the larger veins. The wall rock is altered near the vein, and a band of clayey ''gouge'' is found generally on both footwall and hanging wall. Along the Mount Champion vein the alteration of the wallrock may be traced to a distance of twenty to twenty-five feet from the vein, and disseminated pyrite occurs in noticeable amount for at least fifteen feet from the vein at some places. The amount of pyrite present is, roughly, inversely proportional to the distance from the vein. The wedge-shaped segment of quartz monzonite formed by the intersection of the two faults in the Mount Champion mine is found to contain a considerable amount of disseminated pyrite accompanied by small amounts of gold. In general the amount of alteration of the wall rock, and the distance from the vein to which alteration extends, are proportional to the size of the vein.

The ore shoots are irregular in width, tenor and position within the veins. They are usually sufficiently definite to be followed, and may occasionally become nearly as wide as the vein. The streak or ore shoot is sometimes found near the center of the vein, but the more common position is along either hanging wall or footwall. In the Mount Champion vein the shoot not infrequently divides into two branches, one of which generally is near one wall. No relation has been observed between tenor and position of the shoot, or between width and tenor.

RELATION OF THE VEINS TO THE QUARTZ PORPHYRY DIKES

Most of the prospectors working in the district assume that there is a direct genetic relationship between the ore deposits and the quartz porphyry dikes. They have therefore prospected extensively along the dikes, sinking shafts or driving tunnels alongside them in search of veins which shall emanate therefrom. The fact that such dikes are cut by the workings of the Mount Champion, Gordon and Fidelity mines is cited as proof that such a relation exists. Some have erroneously cited the work of Spurr and Garrey (U. S. Geol. Survey Professional Paper 63) in support of this view.

After two seasons spent in the Twin Lakes district, the writer is convinced that there exists no direct relation between the dikes and the gold quartz veins. There is, however, an important indirect relation, in that both were formed as a result of the same general period of igneous activity. The belt in which the intrusive porphyries occur is in general a belt rich in mineral deposits, but there is no evidence that the formation of the ores has been in any way dependent upon the dikes themselves.

ORIGIN OF THE ORES

Nature of the Ore-Bearing Solutions—The solutions from which the vein materials were deposited must have been of a relatively simple type. Few minerals were carried and all of these are found in perfectly normal associations. Quartz, pyrite and galena are the only minerals present in a majority of the gold-bearing veins. Gold is readily precipitated from solutions by many sulphides,[72] but especially by pyrite and galena, hence the association of gold with these accessory minerals is to be expected.

It may be assumed that the magma from which the quartz porphyry dikes were derived was intruded at such depth that its main body is not now exposed at any place near the Twin Lakes district. This assumption is based on the work of a number of geologists, summarized by Spurr,[73] whose argument will be accepted without repetition here. As the intrusion progressed doming must have occurred (although evidence of such movement is lacking in the area studied) and some fracturing of the overlying rocks as well. Into these fractures, no doubt, there were extended fingers or apophyses of the magma, but the distance to which they extended was not great. Because of the great depth of the intrusion cooling progressed slowly, yet gradually the outer portion of the intrusive mass became solid, with a resulting decrease in volume. These volume changes were produced by (a) change from a liquid to a solid state, and (b) loss of the volatile constituents of the magma.

As cooling and solidification continued the water vapor and other mineralizing agents were expelled from the magma and passed upward through the constantly forming fractures in the overlying

[72]Clarke, F. W., U. S. Geol. Survey Bull. 616, p. 648, 1916.
[73]U. S. Geol. Survey Prof. Paper 63, p. 132, 1908.

rocks. Beginning their upward journey as superheated gases, they must have become, ere long, either liquids or solids. The most prominent vapor present in the magma probably was that of water, which, as soon as it became liquid, began to absorb not only its companion gases and salts, but sundry materials from the rocks through which it passed. Such a magmatic exhalation, originally simple, might easily become vastly more complex before reaching the end of its journey.

As the solutions continued to move upward, becoming cooler and encountering gradually decreasing pressures, there must have been a point beyond which their solvent powers decreased, and the dissolved materials began to be precipitated as veins in the fissures which served as channels of circulation. Veins formed in this manner might consist not only of minerals contained in the original exhalations, but of others gathered from the rocks along the way. The order of precipitation of the various minerals is dependent on many factors, which cannot be discussed here.

In that type of deposit, which is best illustrated by the Mount Champion, Fidelity, Gordon and Eureka veins, the ore mineral is native gold, associated with pyrite and galena, in a quartz gangue. In general the veins in the Twin Lakes quartz monzonite porphyry contain larger amounts of galena than those in the pre-Cambrian formations. This may be the result of passage through a different kind of country rock, and one which contains a higher lead content.

The gold and small amount of silver which occur in all of the veins may have come either from the magma or from the country rock traversed by the ascending solutions. Probably the magma was the source, but there is no proof that such is the case.

THE MOLYBDENITE ORES

The veins in the vicinity of Red Mountain which carry molybdenite are always so closely associated with the Red Mountain rhyolite that it appears nearly certain that the flow is the source of the mineral. Molybdenite is disseminated in or partially concentrated in the rhyolite itself, along with finely disseminated pyrite. The occurrence of molybdenite in granites is common[74] and its occurrence in a rhyolite is not surprising.

[74]Clarke, F. W., U. S. Geol. Survey Bull. 616, p. 335, 1916.

ORIGIN OF THE OPENINGS

As pointed out on a previous page, the deep-seated intrusion to whose exhalations have been ascribed the formation of the veins, gave rise to faulting at two distinct periods. The first period of faulting occurred at the time the magma was injected, the second during the time of cooling and shrinking.[75] Many of the openings produced by the first period of faulting were filled by the dikes of quartz porphyry. Those of the later period were filled with vein material.

It is believed that a majority of the veins occupy fault fissures. This may be proved in many cases. In no vein in the district has the displacement been great, although in some large fissures, such as the one occupied by the Mount Champion vein, the shattered zone is fifty feet or more in width, while the width of the vein is but fifteen to twenty feet at the most. No displacement can be detected although it may be present, for the vein passes through massive rock only.

SUMMARY

The ores of the Twin Lakes district appear to have been formed by heated ascending waters or vapors, or both, which had their origin in deep-seated intrusions. Ore deposition followed shortly after the intrusion of the quartz porphyry dikes, and the veins are located in fault fissures produced principally by reason of the shrinkage of the solidifying intrusive body. The quartz porphyry dikes were sent out from the same magma, but are independent of and earlier than the ores.

EFFECT OF GLACIATION ON THE VEIN DEPOSITS

The Pleistocene was a period of intense erosional activity, and during that time hundreds of feet of rock were removed from the valleys as well as from the hills of the district. In addition to the rock actually worn away by the abrasion of the ice, there were removed practically all the accumulated debris which obscured and partially protected the bedrock from the agents of weathering. After the disappearance of the glaciers, therefore, there ensued another period of super-normal erosion which is still in progress in many parts of the area.

The result of the activity of the two great erosional agents, ice and water, was the lowering by several hundred feet, of the

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[75] Spurr, J. E., Relation of Ore Deposition to Faulting. Econ. Geology XI, p. 617, 1916.

surface of the entire region. And the time that has elapsed since the close of this period of super-normal erosion is relatively short. These two facts are important in the consideration of the ore deposits.

DEPTH AND CHARACTER OF THE OXIDIZED ZONE

In the oxidation of a sulphide ore body time is an important factor. The ore body must, of course, be permeable; it must be so situated topographically that surface waters will be retained by or in it in considerable amount, and it must be sufficiently above permanent ground water level to permit the downward moving waters to circulate freely. But with all other factors favorable, there must elapse a great length of time, during which the oxidizing agents are active, in order to permit the formation of a deep oxidized zone.

The intense glaciation of the Twin Lakes district has been unfavorable to the formation of a deep oxidized zone. Glacial erosion has removed not only the mantle of debris, which reduced runoff and retained the surface waters until they were able to enter the ore bodies beneath, but through its plantation of the veins themselves has removed even the oxidized material already formed previous to the Pleistocene. The very shallow depth to which the veins are oxidized proves that any pre-Pleistocene oxidation which may have existed, reached only to depths that were greatly exceeded by the Pleistocene erosion. In other words, the present outcrops of the veins lay far below the bottom of the oxidized zone as it existed at the beginning of the Pleistocene. And no more oxidation should be expected to occur in the veins of the district than could well be produced in the relatively short time since the close of the Pleistocene.

The depth to which oxidation has occurred varies somewhat according to topography, being greater in those veins located on the peaks, and less in those of the valleys. In general, the depth of thorough oxidation is less than ten feet, and sulphide ore frequently is found in outcrops.

POSSIBILITY OF SECONDARY ENRICHMENT

In ore deposits of the type found in this district the secondarily enriched zone would normally occur at the lower limit of the vadose circulation, or, in other words, at the top of the permanent water table. The minerals whose addition at that level should produce enrichment, would have to be leached from the upper portion of the ore body, and largely from the oxidized zone. But inasmuch as the ground water level in regions of high altitude is not constant, the enrichment might take place within a comparatively wide zone, corresponding to the distance between the upper and lower limits of oscillation of the ground water level.

It has been pointed out before that a majority of the veins have been truncated at a level usually below that of the pre-Pleistocene zone of oxidation. The present outcrops, therefore, are either at or beneath the levels at which enrichment might be expected as a result of pre-Pleistocene processes. If any enrichment occurred previous to the glaciation of the region, the present outcrops are either (a) parts of the enriched zones, or (b) were below such a zone which has now been removed by erosion.

In summary it may be said that the chances are remote of finding a secondarily enriched zone in any of the auriferous quartz veins of the Twin Lakes district. It is possible that the portions of many veins represent the richest parts of these outcropping ore bodies. However, if the present outcrops represent zones lower than any former enriched zone, no marked change of tenor in depth should be expected.

PLACERS

The first mining operations conducted in the Upper Arkansas Valley were of the placer type. Lode mining was a later development and resulted logically from the placer operations, when the miner sought to follow from the alluvial deposits the golden trail which should lead to the source of the metal. Thus settlements were made first in the vicinity of Granite and Twin Lakes by placer miners, who gradually extended their prospecting up the valley. The early miners, however, as well as the later ones, met with indifferent success, for the glacial gravels of Lake Creek valley seldom showed even a ''color'' in the pans. Absence of gold in paying quantity in the gravels led to the belief that auriferous veins do not occur on the mountain sides above, and probably this view did much to discourage prospecting.

Claim maps of the district show many placer claims along Lake Creek, and many of them are patented. The majority have been taken up solely for the sake of the timber growing upon them, and which it was intended to use in nearby lode mining operations. Only a few have ever been worked, of which all but one have long since been abandoned. At Everett, Mr. W. S. Lorimer, of Philadelphia, Pa., has installed a rather extensive plant for the purpose of sluicing the alluvial gravels which fill an expansion of Lake Creek valley immediately below the forks. The property has been operated intermittently for several years, but no data are available regarding the results obtained.

Effect of Glaciation on Placer Deposits—Placer deposits are formed by concentration, usually through the agency of running water, of heavy minerals contained in the products of rock decay and weathering. The concentrations occur most commonly in stream channels. It is obvious that by the passage of the glaciers through the gulches and valleys of the Lake Creek system, the accumulations of pre-glacial gravels were entirely removed and carried down into the Arkansas Valley. Here the gravels were discharged to form morainal and outwash deposits. Any placer material which may exist in the valley at the present time must have been formed since the Pleistocene, and inasmuch as we have seen that following the disappearance of the ice the erosional agents began work on nearly fresh surfaces, large quantities of maturely weathered rock waste cannot be expected. The filling of the valley consists largely of imperfectly weathered material, much of it very coarse, and poorly assorted.

In the vicinity of the Twin Lakes, and for a short distance above them, most of the gravels may be considered as placer ground. Whether the ground is workable remains to be proved. But above the first falls of Lake Creek the chances of finding payable placer gravel are negligible.

Future of Placer Mining in the District—As shown above, the effects of glaciation have been to render remote the possibilities of finding workable placer deposits above the first Falls of Lake Creek. Even should the gravels above that point show a small gold content, the preponderance of large boulders in the stream beds would increase the operating expenses to a prohibitive figure.

The very successful operation of the dredge on the Derry Ranch in the Arkansas Valley, below Twin Lakes, has shown that large boulders are not necessarily insuperable obstacles to dredging, but it must be remembered that the gold content of the Arkansas gravels is many times greater than can be expected of those in Lake Creek valley.

PRACTICAL CONSIDERATIONS

DEVELOPMENT OF THE DISTRICT

Mode of Occurrence of the Ores—All known ore deposits of the district are of the vein type, with dips that closely approach the vertical. The post-mineral faults are small, and their shattered zones narrow. The structural problems encountered in the development of the ores are simple.

Irregularity of Values—The irregular or spotty character of the ores renders it very difficult to estimate the value of a property. The tenor of ore is high in many of the small veins, yet the possibility that either the ore shoot, or even the vein itself, may play out suddenly along dip or strike must be considered. No reliance can be placed on the continuity of the ore shoots, and amount of ore available in any given mine must be considered to be merely that actually developed.

Metallurgical Treatment—The ores are simple, and their metallurgical treatment offers no especial difficulty. At the Mount Champion mill the low-grade ores, carrying from $5.00 to $12.00 in gold per ton, are treated profitably by amalgamation and concentration. The recovery by this method, although yielding a profit, is said to be unsatisfactory, and the management contemplate the installation of a somewhat different type of mill.

The high-grade ores from all of the properties have been shipped directly to the smelters, which report no difficulty in treating them.

There appears to be no reason why cyanidation cannot be used successfully in the treatment of the low-grade ore, provided it can be found in sufficient amount to justify the erection of the plant.

Transportation—Lack of transportation facilities and poor trails are formidable obstacles in the way of developing other than high-grade deposits. Access to the region is had only by trail from Twin Lakes, and this route is unsuited at present for the economical transportation of heavy loads. From Everett, which is near the center of the district, the distance to the nearest shipping point on either the Denver and Rio Grande or Colorado Midland railroad is about fourteen miles. The town of Granite is somewhat less than three miles farther. With the completion of the new state highway through the valley it may soon be possible to use auto trucks for hauling, and thus materially decrease the grade of ore that can be profitably mined.

Where the mines are located on elevated peaks above the valley, trams are necessary. At the Mount Champion mine, an electrically-operated tram over 6,000 feet in length, extends from the mine near the top of the mountain to the mill in the valley of the Halfmoon. At the Gordon mine a gravity tram has been installed, but never placed in operation.

Power—It is a safe estimate that in nearly every part of the district sufficient power can be developed from the streams to operate all the mines that will ever be located there. From the head of Lake Creek to its mouth there is a fall of almost 2,500 feet, and during the working season the volume of the stream is large. Most of the tributaries to Lake Creek are hanging valleys, hence at their mouths the fall to the level of the main stream takes place within a very short distance. Such a condition is ideal for the location of small turbine-operated power plants.

At the Miller mine, sufficient power is produced for the operation of the fifteen-stamp mill, sawmill, and machine shop, by a water turbine which utilizes the water of Lake Creek. The intake is located about one-half mile above the mill.

Climate—With proper arrangements, underground work in most parts of the district can be carried on during the entire year. The heavy snowfall and the numerous slides which occur each winter, make it impossible to haul ore for more than about eight months per year. Mills located in the main valley should be able to operate nearly the entire year, except when the snowfall is especially heavy.

PROSPECTING

General—It is believed that the information contained in the foregoing pages may, if properly interpreted, assist materially in prospecting for other ore bodies, and in developing those already found. This assistance may be given in several ways:

(a) By pointing out the localities or the indications which should be avoided.

(b) By suggesting promising localities which seem to merit investigation.

(c) By suggesting methods for prospecting and developing the claims, which shall give better results than the hit-or-miss system now in vogue.

Areas Which Should Be Avoided—In general, areas of schist and gneiss are less favorable for the development of strong veins than areas of quartz monzonite (granite) diorite or quartz diorite. When the schist has been intensely injected by granitic rocks, as in the Mount Champion area, the country rock may be considered as being granitic.[76]

Veins of the Mount Champion type should not be expected in areas of the younger volcanic rocks, such as the Red Mountain and Grizzly Peak rhyolites. Apparently the chances of finding payable ore bodies in these formations are not great.

Placer mining above the mouth of Lake Creek gives no promise of success.

None of the veins should be expected to become enriched at depth.

The quartz porphyry dikes have no direct genetic connection with the ores, and the policy of drifting along them in search of mineralized leads is not to be recommended.

Highly siliceous pegmatite dikes may resemble veins and often have been mistaken for them. Absence of banding parallel to the walls, the presence of feldspar (or kaolin) with the quartz, and a nearly total absence of pyrite, distinguish the dikes from veins.

Favorable Areas—Areas in which the Mount Champion quartz monzonite (granite) is the country rock appear to be favorable for the development of strong veins. The same is true of the Twin Lakes quartz monzonite porphyry. However, it is not advisable to prospect the lower parts of the valleys until the higher hills have been thoroughly investigated. All of the workable veins thus far discovered have been above timber-line, and there is reason for believing that the conditions for the formation of veins were better above that elevation than below. Timber-line itself, of course, had no effect.

Methods of Work—The time-honored method of prospecting by searching for mineralized ''float'' and following these fragments up to the source, probably cannot be improved upon as a means of first locating metalliferous veins. It is, in fact, the only possible way of locating the veins of this district.

On one claim visited by the writer two nearly parallel tunnels have been driven into the pre-Cambrian quartz monzonite, the entrances being only fifty feet apart. Such a method of prospecting is utterly wasteful, as a cross-cut from the first tunnel driven

[76]Note: The term "granite" is used here in the sense of "granitic rocks," as it is more familiar to prospectors than the more definite petrographic terms.

would have made it unnecessary to drive the second. The expense of driving the cross-cut would have been about one-third that of the second tunnel.

Because of the variable character of the ore, both vertically and horizontally, the method of prospecting by merely driving an adit along the strike of the vein is not wise. A raise, or winze started at no great distance from the surface will often show immediately the wisdom or futility of further work. For it is not often that a really strong vein will be found to play out in all directions, and the obvious conclusion should be that a vein which fails to hold its width in either a vertical or horizontal direction is unworthy of attention. This view has not always been taken, however, for many tunnels have been driven along mere persistent cracks or crevices, which never attain a width greater than a few inches.

There is a general relation existing between the width of a vein and its linear extent. Thus one should not expect that a stringer only a few inches in width would be traceable for any great distance either horizontally or vertically. The prospecter is usually too optimistic about the possibility of his vein "opening out" a little farther from the surface.

On the bare hillsides of the Sawatch Range it should be possible to gain a fair idea of the value of a vein by tracing its outcrop on the surface. It is much easier to do this by trenching on the surface, than by driving an expensive tunnel through the solid rock beneath. Neither method is, of course, infallible. But it may be set down as a pretty sure thing that any "fissure vein" which is not sufficiently wide and persistent to be traceable at the surface, will not be traceable twenty or thirty feet below, which depth is about what the average tunnel maintains for its first 100 to 150 feet.

In summary, it is suggested that more extensive and careful surface prospecting precede the driving of long tunnels. Also that a number of shallow shafts sunk along the strike of a vein, will often provide a larger amount of information concerning its character, and furnish it at a smaller cost, than would a tunnel which could open the same amount of ground.

CHAPTER VI

MINING PROPERTIES OF THE DISTRICT

INTRODUCTION

In the following pages an effort will be made to describe briefly a number of the properties of the district. The data given, with few exceptions, such as the results of assays, have been obtained by examination of the property itself. Not all claims are discussed, and it should not be assumed that a property has no value, simply because it is not mentioned. Many have been neglected for several years, and their workings are filled with ice and water; a few have been locked up; in others the development accomplished is so slight that the only description possible is a statement of the depth of the prospect hole. Obviously these should not be given space here.

LACKAWANNA GULCH SECTION

EUREKA LODE

The group of claims being operated by the Eureka Mining Company, near the mouth of Mountain Boy Gulch, are developed under the name of the Eureka Mine. The claims now being worked are the Saturday Night, Saturday Night No. 2 and Eureka No. 2. Clyde Balkewill is superintendent.

Development is accomplished through a single adit, which intercepts the ore body at a distance of about 450 feet from the portal. The vein has been followed along its strike for some 500 feet, and five raises, the highest being 72 feet, have been driven from the tunnel level. Near the northern end of the drift a 60-foot winze has been sunk. The plan of the workings is shown in Figure 20, the ore shoot being designated in black.

The ore body is a vein of rather variable width, striking N. 32° E., with an attitude which varies but little from perpendicular. The width ranges from a few inches to 10 feet or more, but usually is from 3 to 5 feet. Three, and possibly four faults, all having

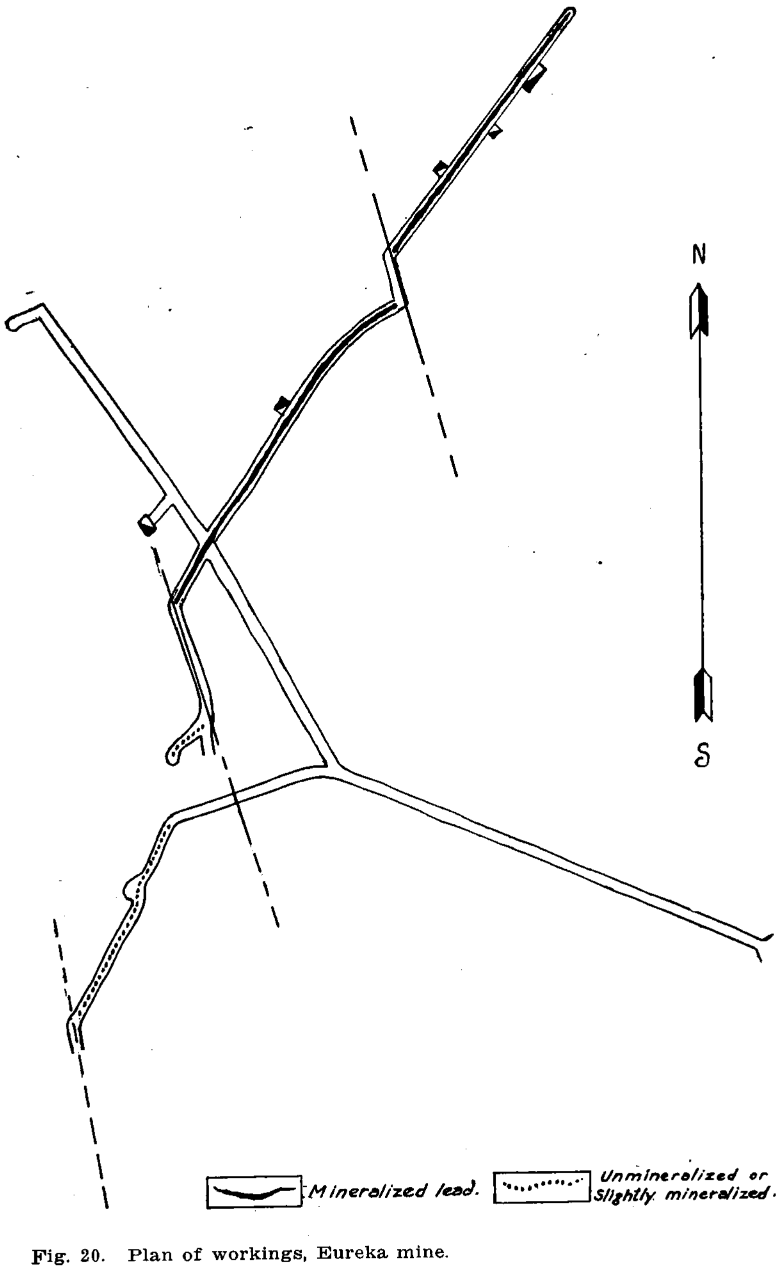


Fig. 20. Plan of workings, Eureka mine.

slight throw, cut the vein, as shown in the sections, Figures 21 and 22, producing in one place an offset of 22 feet, at another one

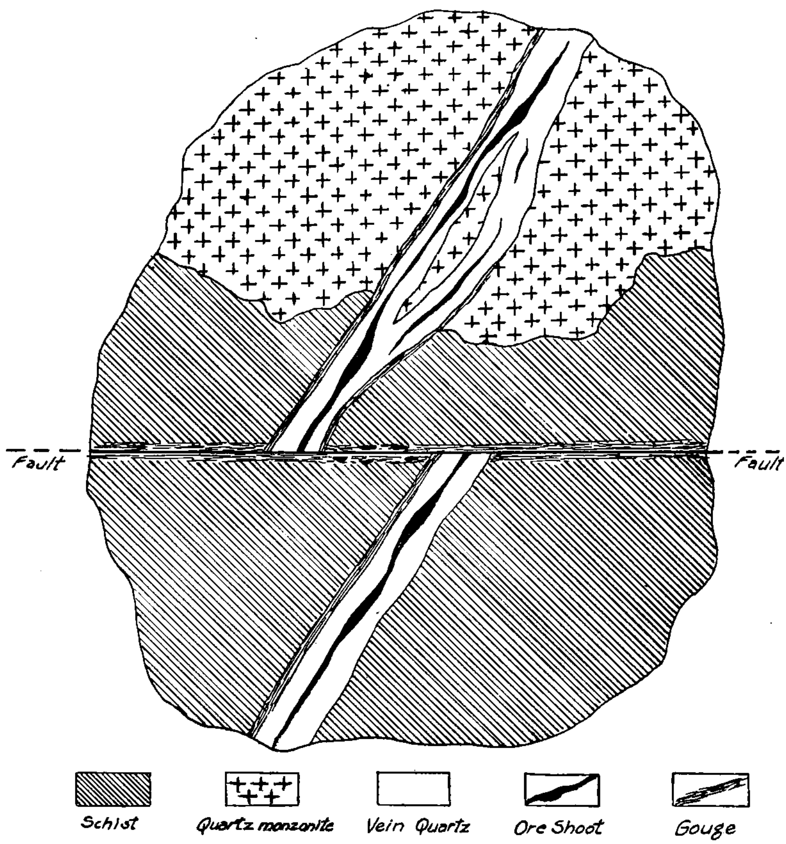


Fig. 21. Ideal cross section of Eureka vein.

of 60 feet. The presence in the ore of many fragments of country rock, as well as the irregularity and persistence of the vein seem to characterize it as a filled fault fissure.

The ore mineral is native gold, associated with pyrite. The gangue is coarse, white quartz, usually showing crustification, the pyrite being arranged roughly along the lines of banding. No galena occurs. The pyrite and its associated gold are segregated into rather definite shoots whose width and position within the vein are not constant.

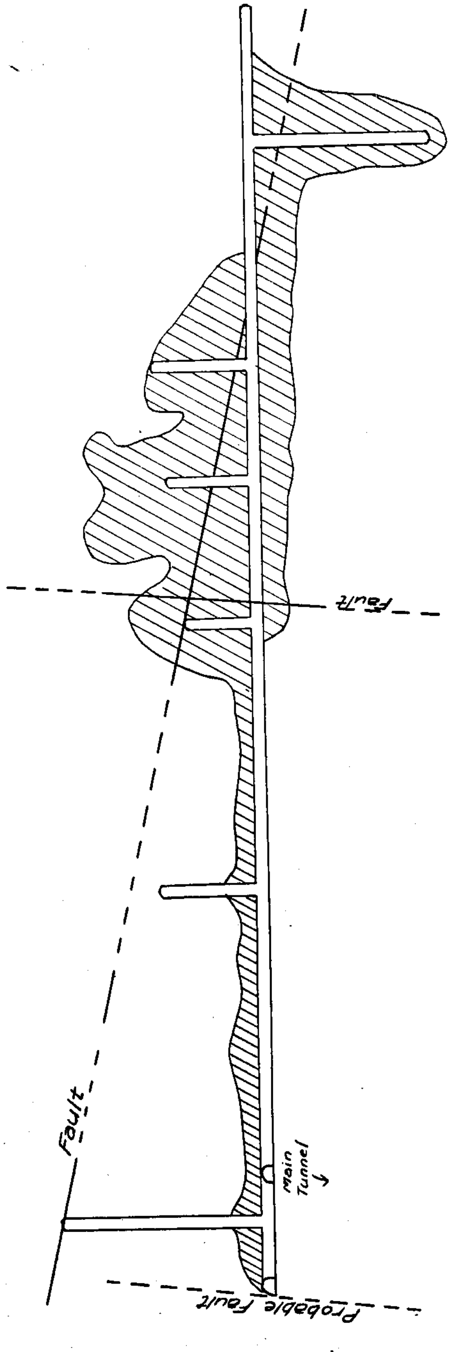


Fig. 22. Generalized section along vein. Eureka mine.

The faults are of later origin than the vein, for they cut and offset it. One, however, is apparently earlier than the mineralization, for although the same gangue continues south of this fault (B-B, Figure 20), the values contained are small and the ore is not workable, at least under present conditions. It may be that further exploration of the southern extension of the vein will prove that this disappearance of payable ore is due simply to the spotty character of the mineralization. In such event, it might be expected that the values would again increase. However, it is pretty clear that the fault B-B is in some way responsible for the leanness of the south end of the vein. The most probable explanation seems to be that the fault plane so deflected or cut off the mineralizing solutions that the part of the vein lying to the south received but meager enrichment.

Thus far it has been possible to ship only the high-grade ore. The ore is hand sorted, the high-grade sacked and carried by burros to Brumley, whence it must be hauled by wagon to the siding at Twin Lakes station, a distance of eighteen miles. The low-grade ore is thrown on the dump, with the expectation that at some later time it will be milled.

MILLER GROUP

The considerable block of claims which compose this group is located on the west side of Mount Champion near the mouth of Lackawanna Gulch. All are owned by the Miller Gold Mining, Milling & Tunnel Company, of which J. G. Buehler is president. Three tunnels have been driven, the upper of which, located nearly a thousand feet above Lake Creek, has been filled with ice for some years, and hence could not be examined. The two lower ones, known respectively as Mauser No. 1 and Mauser No. 2, are open and are described herein.

A completely equipped mill has been erected in the valley just above the junction of Lackawanna and Lake Creeks. Water from Lake Creek operates a turbine which furnishes power to the 15-stamp mill, machine shop, sawmill and compressor. The mill has never been put in operation.

Mauser No. 1—The tunnel follows a small stringer for about 70 feet in a northeasterly (N. 82° E.) direction. The country rock is gneiss and schist, much broken and altered. A thin quartz vein, with a maximum thickness of 16 inches, constitutes the ore body.

Small amounts of gold occur with pyrite in this quartz, but the quantity of ore is not great. The vein pinches out at a distance of 70 feet from the portal of the tunnel, and practically disappears at 20-30 feet below the tunnel level.

Mauser No. 2—A thin vein of greyish quartz, carrying some pyrite and a small amount of gold, has been cut at the breast of the tunnel. The vein dips 73° in a direction North 66° East.

The country rock is gneissic with a small amount of schist scattered throughout. The metamorphic rocks are cut by irregular streaks of a coarse, garnetiferous pegmatite, which is much younger than the country rock. The pegmatite is composed of quartz, orthoclase, almandite garnet, muscovite, and some secondary chlorite. Some alteration is noted, but no more than would be expected in a body of easily-altered rock occurring in a broken zone within a short distance of the surface.

BROTHER LODE

A tunnel has been driven into much altered alaskite in such manner as to parallel a quartz porphyry dike. A cross-cut has been driven into the dike, but does not extend through it. The dike is younger than the alaskite, which has been much altered, possibly as a result of the intrusion. It is very open textured, soft and carries small disseminated crystals of pyrite. Assays show that the rock is of no value as ore.

INDEPENDENCE LODE

A short tunnel exposes a twelve-inch quartz vein cutting gneiss and schist. The quartz is coarsely crystallized and large open spaces lined with quartz prisms are common. Pyrite and galena are scattered sparsely through the quartz, but no well-defined pay streak can be seen. The quartz and pyrite are intergrown in such manner as to indicate that much of the quartz is later than the pyrite.

D. M. ELDER CLAIM

Located on Lackawanna Mountain opposite Mountain Boy Gulch. A quartz vein, varying from 6 inches to 18 inches, outcrops at the surface. The strike is N. 62° E. and the dip is about 36° to the southeast. This property was operated for a time about the year 1882, and an incline shaft was sunk on the vein to a depth of 25 to 35 feet. At the bottom of the shaft the vein is said to be nearly 4 feet in width, but is too lean to be worked. Ore removed nearer the surface assayed as high as 2 to 3 ounces of gold per ton.

The vein consists of coarse, comb quartz, carrying irregularly distributed pyrite and a small amount of galena. In some fragments of the ore found on the dump galena masses have been recemented by pyrite, while in other fragments fractures in pyrite have been recemented by quartz. The workings are filled with ice and it was not possible to determine whether this reopening of the vein is of more than local occurrence.

OZARK GROUP

This group is situated on the east side of Mount Champion, just west of the pass between Lackawanna and Halfmoon Gulches. Little work has been done on the claims except through advanced laterals from the Mount Champion mine. The large vein being worked in the Mount Champion property extends into the Ozark No. 1 and Davis No. 2 claims, and is being worked by the Mount Champion Mining Company through an extension of the lower adit. The vein is described in connection with the Mount Champion property.

COLUMBINE LODE

On the west side of Lake Creek, about one mile north of Lackawanna Gulch, a tunnel has been driven on a vein-like body of quartz-feldspar pegmatite. A few feet from the surface the "vein" plays out, but the tunnel has been continued along a crevice. In a second tunnel, located above and to the northwest of the first, yet on the same vein-like dike, there is found a small amount of mineralized quartz. This apparently occurs as stringers in the pegmatite.

LUCKY JIM GROUP

This group, owned by J. M. Knight, of Leadville, is situated on the south slope of Mount Champion, just below the forks of Lackawanna Creek. A tunnel is being driven northwestward into the mountain, but at the time the writer visited the locality the work had progressed so little that no idea of the conditions could be obtained. The country rock is gneiss and schist, much broken and showing some alteration along the small fissures.

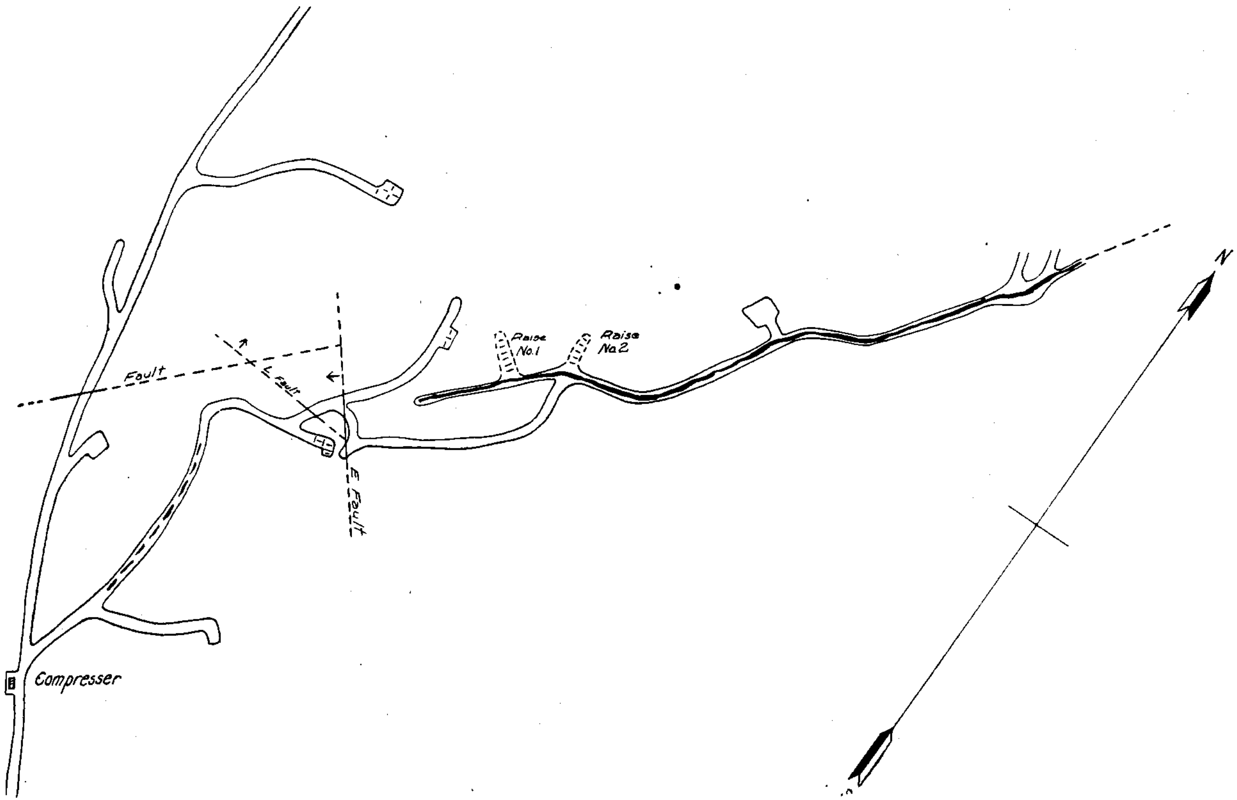
THE MOUNT CHAMPION MINE

This property is situated on the south side of Mount Champion and not far from its top. Development is being accomplished by means of three adits, the upper and lower of which are open to the surface. At present the ore from the intermediate and upper levels is conveyed by chutes to the lower level, through which it is hauled to the ore bins at the surface. An electrically-operated aerial tram, 6,100 feet in length and equipped with 42 buckets, each of 9 cubic feet capacity, carries the ore from the bins to the mill in Halfmoon valley. The mine is electrically lighted along the main haulage ways and is equipped with air drills. Electric power is secured from Leadville. The property is owned and operated by the Mount Champion Mining Company. L. W. Smith is superintendent.

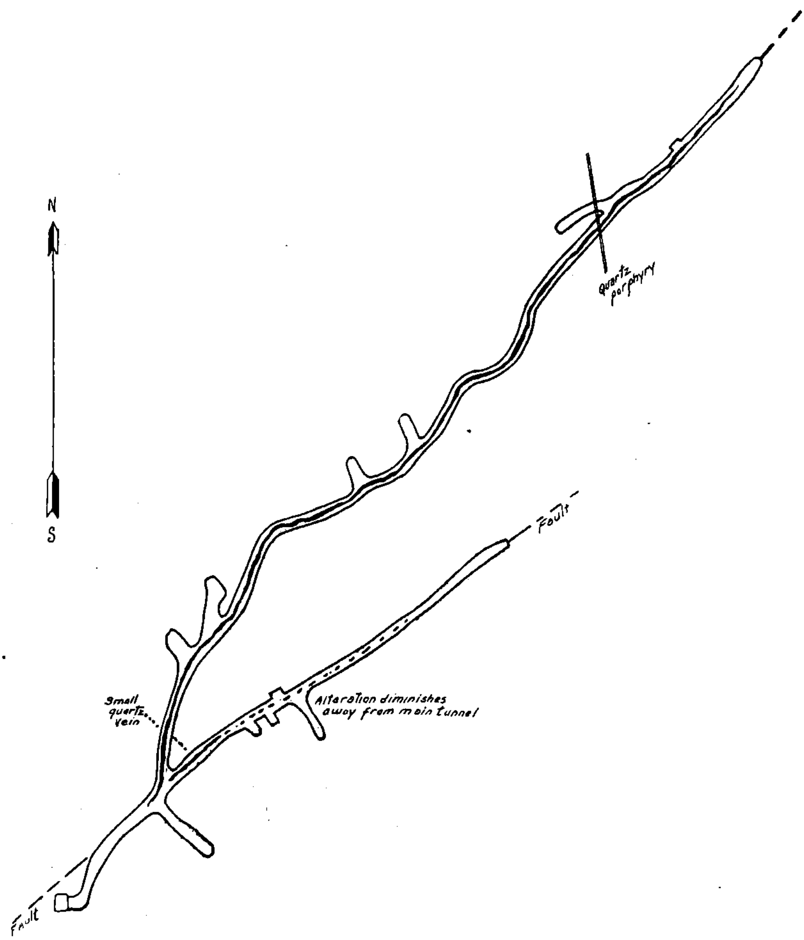
The ore body is a broad quartz vein, ranging in width from 3 feet to more than 20 feet. At its widest point but one wall had been exposed at the time of examination. The trend of the vein is approximately N. 55° E., and the dip is to the southeast. The vein stands in a nearly vertical position, the departure from the vertical varying in different levels and from place to place along the same level.

A number of faults cut the vein, the more important being shown in the sections (Plate II d). The vein itself occupies a fault fissure, which is designated as the ''K'' fault. This fault is a single strong fissure in both upper and lower levels, but in the intermediate there appears to be a slightly divergent branch. The mineralization of the branch is unimportant. Two lesser faults, ''E'' and ''L,'' cut the vein on the lower level, cannot be identified on the intermediate, but appear again in the upper. It may be said, however, that the identification of the ''L'' fault in the upper level is not entirely satisfactory and the one so designated on the map may prove to be another. The relation of the three important fault planes may be described as follows: ''E'' dips to the southwest, ''L'' dips to the northeast, the two intersecting somewhere below the lower level and forming a trough-like figure, through which the vein passes obliquely. The block of monzonite which is bounded by the two fault planes has been mineralized to such an extent that it may be regarded as mill ore, although the amount of gold present is not more than $2 to $4 per ton.

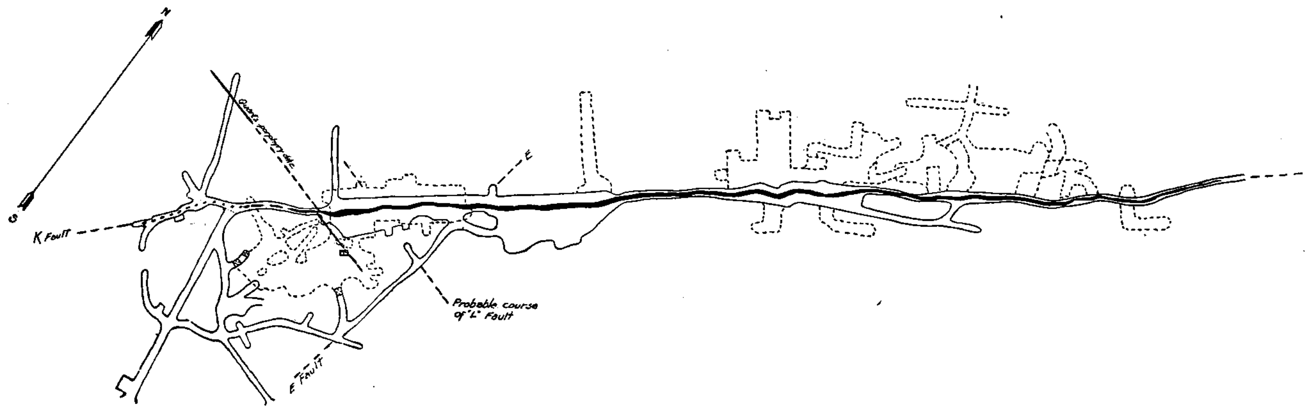
The country rock is Mount Champion quartz monzonite, except at the extreme west end of the workings, where some schist and



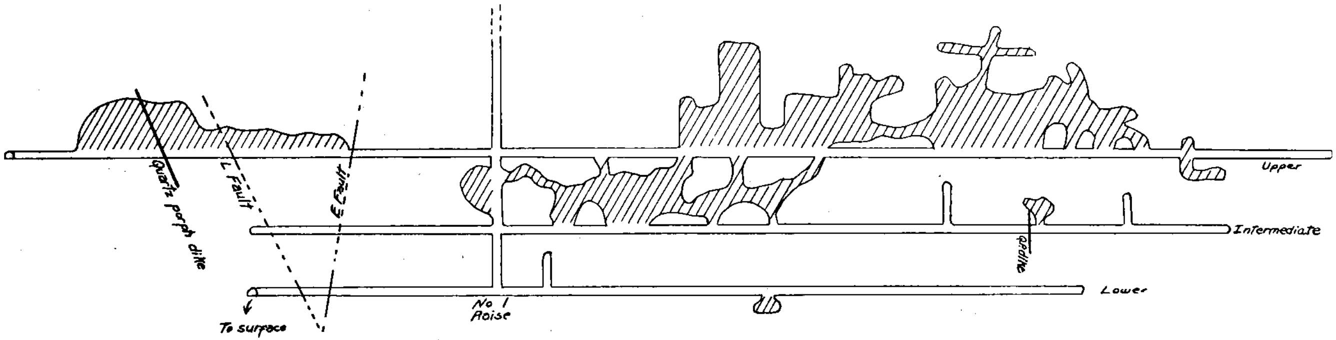
Horizontal plan of lower level. Mount Champion mine.



Horizontal plan of intermediate level. Mount Champion mine.



Horizontal plan of upper level. Mount Champion mine.



Vertical section along the vein. Mount Champion mine.

gneiss appear. The walls are sharp and distinct, with a few inches of gouge separating them from the vein. Alteration and softening of the country rock is noticeable for a considerable distance on either side of the main vein, the amount decreasing with distance from the vein. Small veins containing a soft, talcose clay occur at intervals along the walls, but are not known to be mineralized.

At the western end of the upper tunnel the vein passes from monzonite into gneiss and schist, where it immediately becomes less definite and leaner, until finally the tenor is so low that profitable exploitation is impossible. Apparently the vein dies out, or rather, "feathers out," into a number of small stringers of slightly mineralized quartz which follow chiefly the planes of schistosity, and are locally termed "bedded veins."

It seems clear that the pervious nature of the schists has permitted the escape of the ore-bearing solutions and that these so-called "bedded veins" are intimately related to the main vein.

The ore consists of auriferous pyrite and a small amount of galena, in a gangue of coarse, white quartz. (See Figure 23.)

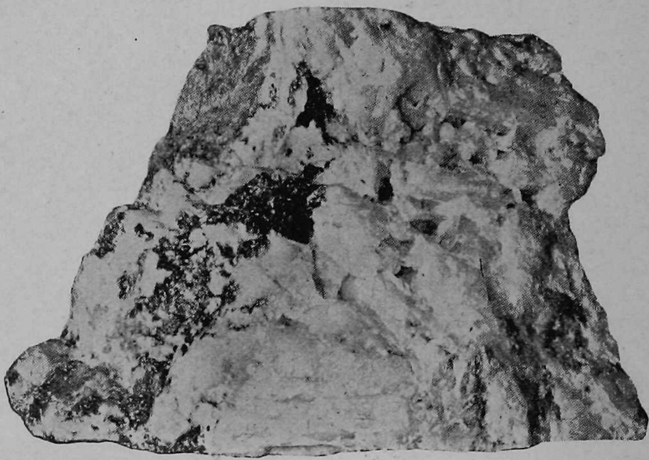


Fig. 23. Ore from the Mount Champion mine. The white mineral is quartz, the black is galena, the gray pyrite. Usually galena is less prominent, but in other respects the ore is characteristic.

Traces of copper occur locally, but the amount is very small. Silver is present in small, but constant amount. Smelter returns average about one ounce of gold to one of silver. The pyrite and galena are of fine or medium texture, pyrite crystals as large as three-eighths inch being rare. Good crystals seldom are seen, and most of the sulphide occurs in solid veins or shoots. The ore shoot is irregular in its habit, following either wall, lying well away from either, or splitting into several branches. The shoot may be traced at least 1,000 feet without a break, although its thickness at some places is reduced to less than an inch. The gold content of the vein is variable, but is more constant than is the content of any other vein of the district.

The work done thus far has failed to show any marked variation of the ore with increasing depth. The vein is now open for a distance of nearly 300 feet on the dip, yet no marked change in physical character or in tenor has been noted. The width remains nearly constant to a depth of 100 feet below the main level.

Treatment of the Ore—The high-grade ore is separated in the stopes, and is shipped direct to the smelter. The mill ore is treated by an amalgamation-concentration process after grinding in ball mills. Concentrates and high-grade ore are hauled by wagon from the mill to Malta, and there loaded on cars for shipment, usually to Leadville.

TWIN LAKES SECTION

THE GORDON MINE

The Gordon or Gordon-Tiger mine is situated on a spur of Mount Elbert, just west of Twin Lakes. It has been worked intermittently by various companies and individuals for over thirty-five years, and a considerable amount of gold is reported to have been taken out. Reliable information regarding the character or value of the ore mined is not available, nor can a great deal be learned by examination at the present time.

The property has been developed through four levels (see Figure 24), all of which are in the Twin Lakes quartz monzonite porphyry. The vein strikes S. 65° W. in the lower levels, and dips to the northwest at an angle of 50° to 55°. It is well defined. The width varies from three to eight feet within short intervals. Gouge is present on both walls, but usually is thicker on the hanging wall. Three quartz porphyry dikes are cut by the third level, and one by the second, all of them being softened, altered, and slightly pyritiferous. They clearly are older than the vein, which cuts through them.

The vein consists of a white or gray quartz gangue carrying free gold associated with pyrite, galena, chalcopyrite and an occa-

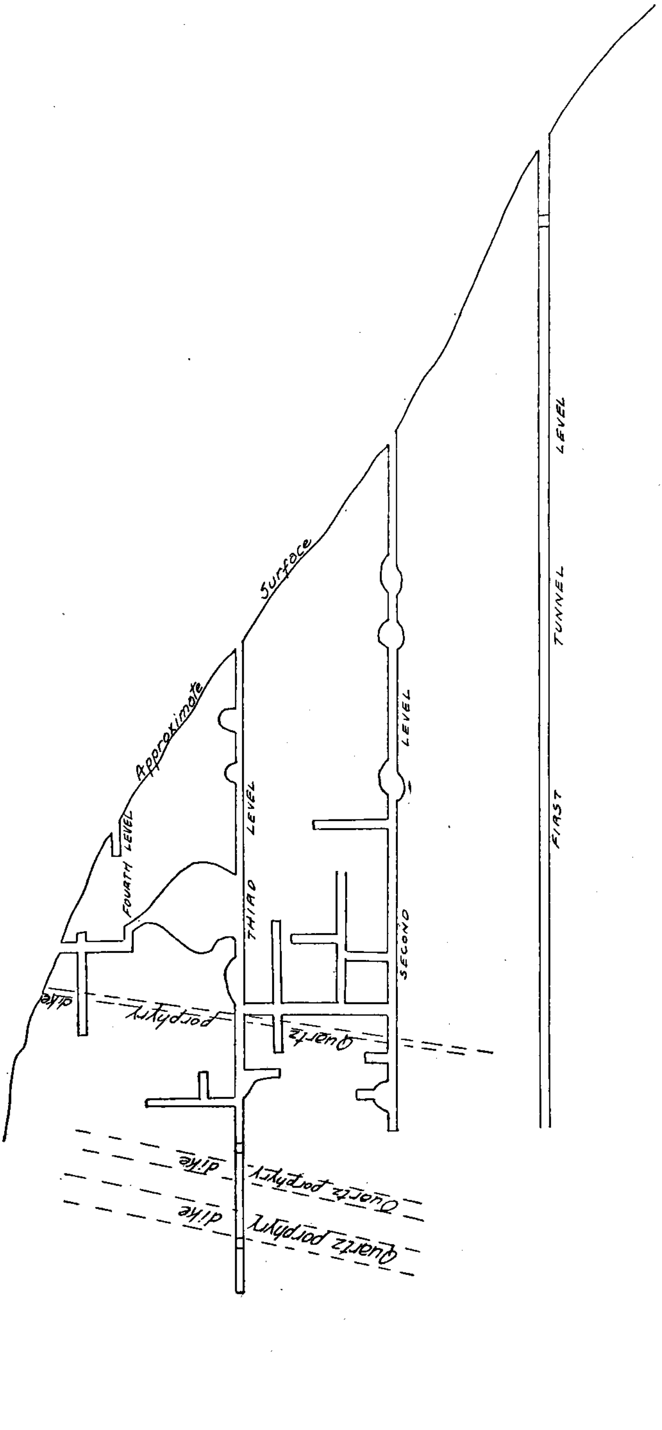


Fig. 24. Vertical section along the vein. Gordon mine.

sional small mass of sphalerite. The ore shoot is very irregular and the ore occurs chiefly in bunches. The policy of past operators has been to remove only the rich pockets, hence the stoping operations may best be described by the term ''gophering.'' At the time of examination it was almost impossible to find more than small masses of ore in place, and owing to the caved condition of many parts of the mine, not even that much could be seen. The material on the dumps gave some information, but such material is very unreliable.

Occurrences of native gold in a matrix of galena and sphalerite are said to have been not uncommon in the lower levels, and several such specimens were seen by the writer in the possession of parties living nearby. Their exact locations in the mine are not known.

In the collections of the University of Iowa is a specimen of ore from one of the upper levels, which illustrates the process of alteration of galena to anglesite. A photograph of the specimen is shown in Figure 25.

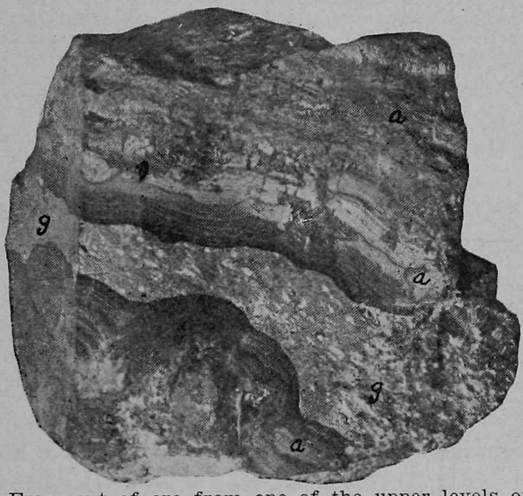


Fig. 25. Fragment of ore from one of the upper levels of the Gordon mine. Shows galena (g) altering to anglesite (a).

FIDELITY MINE

This property is located on ''Bull Hill,'' at the head of Monitor Gulch, and is being operated under the direction of S. E. Smith. Development only is in progress, and no especial effort is being made to take out ore. A broad vein of auriferous quartz has been opened, having a strike of N. 50° E. and a dip of 52° to the northwest. The country rock is Twin Lakes quartz monzonite porphyry.

The ore shoot varies in width from a few inches to two feet, and carries native gold associated with pyrite, in a gangue of white quartz. Crustification is characteristic and both the pyrite and

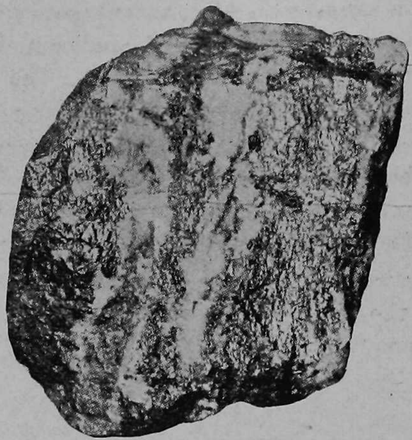


Fig. 26. Ore from the Fidelity mine. The white mineral is quartz and the gray is pyrite. Note the banding. This specimen is characteristic of the pay streak of this vein.

quartz are concerned in the banding (see Figure 26). Small amounts of calcite are of occasional occurrence in the ore. Gouge occurs in considerable thickness on both footwall and hanging wall, but in a few places the vein is frozen to the hanging wall. The gold is associated with the pyrite and the amount of pyrite present is a rough index of the value of the ore.

A cross-cut extending to the east of the main workings intersects a large quartz porphyry dike which trends northwest and southeast, and penetrates it a distance of 50 feet without passing through. The dike is softened and altered in the same manner as in the Gordon and Mount Champion mines. In the Fidelity workings it has not yet been demonstrated whether the dike or the ore is the younger, but it seems probable that the same relation holds here as elsewhere, and that the ore is later than the dike.

MANHATTAN TUNNEL

About two miles above Twin Lakes and on the north side of Lake Creek a nearly straight tunnel has been driven into the Twin Lakes quartz monzonite porphyry for a distance of several hundred feet. No vein is visible at any point. A short distance from the surface the tunnel enters an unaltered quartz porphyry dike and passes through it. This dike is not visible on the hillside above.

SUNSET LODE

Located on the south side of Lake Creek near Willis Gulch. A tunnel follows a thin fissure which trends about S. 20° E. The fissure is partially filled with quartz, but for the most part is merely filled with gouge and constitutes a "mud seam." The amount of quartz seems to be greater at a distance from the surface. Pyrite, galena, chalcopyrite and a small amount of dolomite are found in the vein material. The country rock is a broken and locally altered quartz monzonite porphyry.

RED MOUNTAIN SECTION

ANCHOR GROUP

Embraces a group of claims on the east side of Peek-a-boo Creek opposite Red Mountain and owned by W. E. Mock and George Hartman. Several quartz veins, all dipping steeply to the southeast, outcrop along the cliffs. As shown in the section (Figure 27), the veins are found in both the quartz hornblende diorite

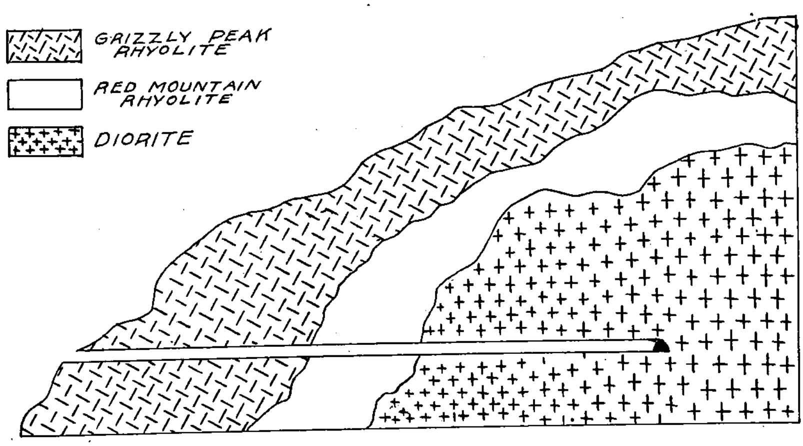


Fig. 27. Generalized geologic section across the Anchor group.

and the hornblende diorite. Nearly all the fractures in these two formations for some distance from the center of the group are found to carry gold, and the larger fissures often contain rich shoots. These larger and richer veins trend about N. 80° E. An improvement in the tenor of the ore is noted at the intersections of fractures. It is said that the ore in the quartz diorite is richer than in the hornblende diorite.

The oxidized zone is very definite, but is only a few feet in depth. The oxidized material is much richer than the sulphides, the enrichment being due to residual concentration, and most of the gold accompanies the limonite. Samples of this limonitic material which has been screened from the ore have assayed as high as 10 to 15 ounces of gold per ton, which is practically the same as the value of the streaks of high-grade sulphide ore. None of the veins has been developed extensively, but in the deepest shaft thus far sunk (about 30 feet on the dip) the character of the vein was found to be practically identical with that at the top of the sulphide zone.

The croppings of these veins are composed of porous, honeycombed, iron-stained quartz, containing many molds of pyrite crystals, usually of small size. The croppings pan well and carry moderately fine flakes of gold. Some masses of gold as large as a pea have been found, but they are rare.

In certain parts of what is known as the "Best Yet" vein, there is found a well-banded, coarsely-crystallized quartz with which is associated a large amount of sericite, usually in coarse flakes. The sericite greatly resembles foliated talc, but is distinguished by its optical characters.

TELLURIUM LODE

This property is situated in Sayers Gulch about one-half mile above its mouth, and is owned by W. E. N. Wright of Twin Lakes. The ore body is a quartz vein in quartz diorite, and the sulphides include only pyrite and galena. There is a variable amount of gold associated with the pyrite. Crustification is common.

BURGE GROUP

This property is located on the north slope of East Red Mountain, and is owned and operated by John V. Burge. A tunnel nearly 1,200 feet in length has been driven directly into the mountain, which is composed almost wholly of Red Mountain rhyolite. No distinct vein has been encountered. The rhyolite is broken and somewhat altered, especially along lines of extensive fracturing, where much soft, clayey gouge has been developed. This gouge frequently contains small bunches of pyrite. The alteration probably has resulted entirely through the activity of surface waters, for the rhyolite is much broken, and affords ready passage for the waters.

Both the fissures and the massive rhyolite carry flakes and stringers of molybdenite. The stringers are sometimes as much as an inch in width, but the more usual occurrence is as very small streaks or flakes. Apparently the occurrence is general.

BWLCHGOCH MINE

The Bwlchgoch mine (so named from a Welsh word meaning "Red Mountain") is located near the head of the South Fork of Lake Creek. A vein trending N. 80° E. has been developed through three levels. The Bwlchgoch is unlike the majority of the mines in the vicinity, in that the ventilation is very poor, and as it had not been in operation for more than a year at the time the writer made his visit, examination of all the workings proved impracticable. The country rock is gneiss, schist and pre-Cambrian quartz monzonite, and there is no indication of the presence of any quartz porphyry dikes.

The ore is a coarse, pyritiferous quartz, with which is associated a large amount of chlorite and talc, which has been developed by alteration of included wall rock. The pyrite is rather coarse, and in the ore now visible in the old stopes there appears to be no well-defined shoot.

A ten-stamp mill has been erected, but apparently never has been extensively operated.

OTHER LODES

The First Discovery Lode is located on the East Fork of Sayers Gulch, not far from the forks. Two nearly parallel tunnels only fifty feet apart have been driven into the pre-Cambrian monzonite gneiss. No well-defined vein can be seen in either tunnel.

On the west wall of the East Fork of Sayers Gulch, and about two miles south of the forks, a broad vein of quartz projects from a cliff of monzonite. The vein at its outcrop is 12-15 feet in width, composed of crustified white quartz, with a small amount of pyrite. A few inclusions of altered country rock are present.

Numerous small slips or joints in the vein indicate that it has been somewhat affected by deformation. Pyrite casts, containing no limonite, are numerous along the outcropping vein, and are found also at the breast of a short tunnel driven into the vein.

This vein was not followed for any distance, but is said to be traceable for a mile or more to the west.

APPENDIX

MINERALS OF THE DISTRICT

The following list of minerals is not exhaustive, and probably does not include all of the species that occur within the district; but it does include all of the common ones and makes brief mention of the places and modes of occurrence:

Albite. A plagioclase. Occurs as an original constituent of the monzonites.

Almandite. Iron garnet. Occurs in the schists of the pre-Cambrian and as a result of contact metamorphism.

Amphibole. (See Hornblende.)

Andesine. A plagioclase. Found in some specimens of monzonite.

Anglesite. Upper levels of the Gordon mine. A secondary mineral resulting from the alteration of galena.

Apatite. Occurs as an inclusion in micas (biotite), in several of the igneous rocks. Also found in the pegmatite dike at the head of the North Fork of Lake Creek.

Azurite. Results from the alteration of a copper sulphide. Found sparingly in the oxidized zones of veins.

Barite. Occurs in veins in gneiss, quartz monzonite and rhyolite near the head of Mountain Boy Gulch.

Biotite. Black mica. An original constituent of most of the igneous and metamorphic rocks of the district.

Calcite. Found sparingly in the veins. A thick vein is found in a shaft on the Davis No. 2 property on Mount Champion.

Chalcedony. Occurs in vugs and veins in the Grizzly Peak rhyolite.

Chalcopyrite. Occurs rarely and in small amount in the veins.

Chlorite. Occurs in the schists and in altered zones of the diorite. Produced by alteration of the ferro-magnesian minerals.

Dolomite. A few small crystals occurred in a sample of ore from the Sunset property near Twin Lakes.

Diopside. Formed by contact metamorphic action on limestone in the pre-Cambrian at the head of the South Fork of Lake Creek.

Epidote. A contact metamorphic mineral. Occurs in gneiss on Lackawanna Mountain, and in veinlets in pegmatite at the head of the North Fork Lake Creek.

Fluorite. Found in small amount in the pegmatite dikes.

Galena. Occurs in a majority of the veins. With pyrite.

Garnet. (See Almandite.)

Gold. Occurs in the quartz veins of the district, always in association with pyrite.

Hematite. Found in small veinlets in an alaskitic dike at the head of Fryingpan Creek.

Heavyspar. (See Barite.)

Hornblende. In the diorite, monzonites and in schists.

Limonite. The brown stain on weathered surfaces of the veins and the brown material which fills the cavities of the oxidized ore is limonite. Formed usually by oxidation of pyrite.

Lodestone. Magnetite.

Magnetite. Occurs in pegmatites. Also in small amount in most of the igneous rocks.

Malachite. Occasionally found in the upper zones of the veins.

Mica. (See Muscovite and Biotite.)

Microcline. An important constituent of the Twin Lakes quartz monzonite porphyry and the Mount Champion quartz monzonite.

Molybdenite. Occurs in small quartz veins and disseminated in the Red Mountain rhyolite. Sayers Gulch.

Molybdite. Molybdic ochre. Formed by oxidation of the molybdenite.

Muscovite. White mica. Occurs in the quartz porphyry dikes. Also in the pegmatites.

Oligoclase. A plagioclase. A common constituent of the monzonites.

Orthoclase. Found in the rhyolites and the pegmatites. Also in small amount in the monzonites.

Plagioclases. (See Albite, Oligoclase, Andesine.)

Pyrite. Occurs in all of the veins. Also disseminated through the Red Mountain rhyolite.

Pyrolusite. Forms the dendrites in fractures in the quartz porphyry dikes.

Quartz. Commonest gangue mineral in all veins. Also is an important constituent of all igneous rocks and most sedimentary rocks found in the district.

Sericite. Found in certain veins, notably those of the Anchor group.

Sillimanite. Forms essential part of biotite-sillimanite schist.

Soapstone. Talc.

Sphene. Titanite. An occasional constituent in the igneous rocks.

Steatite. Talc.

Talc. Occurs in the talc schists of the pre-Cambrian, especially on Sheep Mountain.

Tourmaline. Found in large crystals in a pegmatite dike at the head of the North Fork of Lake Creek.

Turgite. Occurs mixed with limonite in the red coating on weathered surfaces of the Red Mountain rhyolite.

White mica. Muscovite.

Wollastonite. Produced by hydrothermal action on a limestone inclusion in the Grizzly Peak rhyolite at the head of McNassar Gulch.

Zircon. Occurs as small, stout prisms of microscopic size, in certain of the igneous rocks.

INDEX

PUBLICATIONS OF THE COLORADO GEOLOGICAL SURVEY

R. D. George, State Geologist
Boulder, Colo.

FIRST REPORT, 1908. Out of print except A.

A. The Main Tungsten Area of Boulder County, by R. D. George.

B. The Foothills Formation of Northern Colorado, by Junius Henderson.

C. The Montezuma Mining District, Summit County, by H. B. Patton.

D. The Hahns Peak Region, Routt County, by R. D. George and R. D. Crawford.

BULLETINS 1 AND 2, IN ONE VOLUME, 1910:

Bulletin 1: Geology of Monarch Mining District, Chaffee County, R. D. Crawford.

Bulletin 2: Geology of Grayback Mining District, Costilla County, H. B. Patton.

BULLETIN 3, 1912: Geology and Ore Deposits of Alma District, Park County, H. B. Patton.

BULLETINS 4 AND 5, IN ONE VOLUME, 1912:

Bulletin 4: Geology and Ore Deposits of the Monarch and Tomichi Districts, Chaffee and Gunnison Counties, R. D. Crawford.

Bulletin 5, Part I: Geology of the Rabbit Ears Region, Routt, Grand and Jackson Counties, P. G. Worcester, F. F. Grout and Junius Henderson. Part II: Permian or Permo-Carboniferous of the Eastern Foothills of the Rocky Mountains in Colorado, R. M. Butters.

BULLETIN 6, 1912: Common Minerals and Rocks, Their Occurrence and Uses, by R. D. George. Out of print.

BULLETIN 7, 1914: Bibliography of Colorado Geology and Mining, Olive M. Jones.

BULLETIN 8, 1914: Clays of Colorado, G. M. Butler.

BULLETIN 9, 1916: Bonanza District, Saguache County, H. B. Patton.

BULLETIN 10, 1916: The Gold Brick District, Gunnison County, R. D. Crawford and P. G. Worcester.

BULLETIN 12, 1917: Common Minerals and Rocks, Their Occurrence and Uses, R. D. George.

BULLETIN 13, 1918: Geology and Ore Deposits of the Platoro-Summitville Mining District, Rio Grande and Conejos Counties, H. B. Patton.

BULLETINS IN PRESS

BULLETIN 14: Molybdenum Deposits of Colorado, P. G. Worcester.

BULLETIN 15: Manganese Deposits of Colorado, G. A. Muilenburg.

BULLETIN 17: The Twin Lakes Mining District, Lake and Pitkin Counties, J. V. Howell.

TOPOGRAPHIC MAP OF COLORADO, 1913: 40x56: Scale 8 miles to the inch; R. D. George. Supply approaching exhaustion.

GEOLOGIC MAP OF COLORADO, 1913: 40x56: Scale 8 miles to the inch; R. D. George. Supply almost exhausted. If requested, the State Geologist will mark on this map the areas structurally favorable for the occurrence of oil.

BULLETINS READY FOR PUBLICATION

BULLETIN 11: The Mineral Waters of Colorado, O. C. Lester and Harry A. Curtis.

BULLETIN 16: The Uranium-Vanadium-Radium Ore Deposits of Western Colorado, R. C. Coffin.

BULLETIN 18: The Fluorspar Deposits of Colorado, H. A. Aurand.

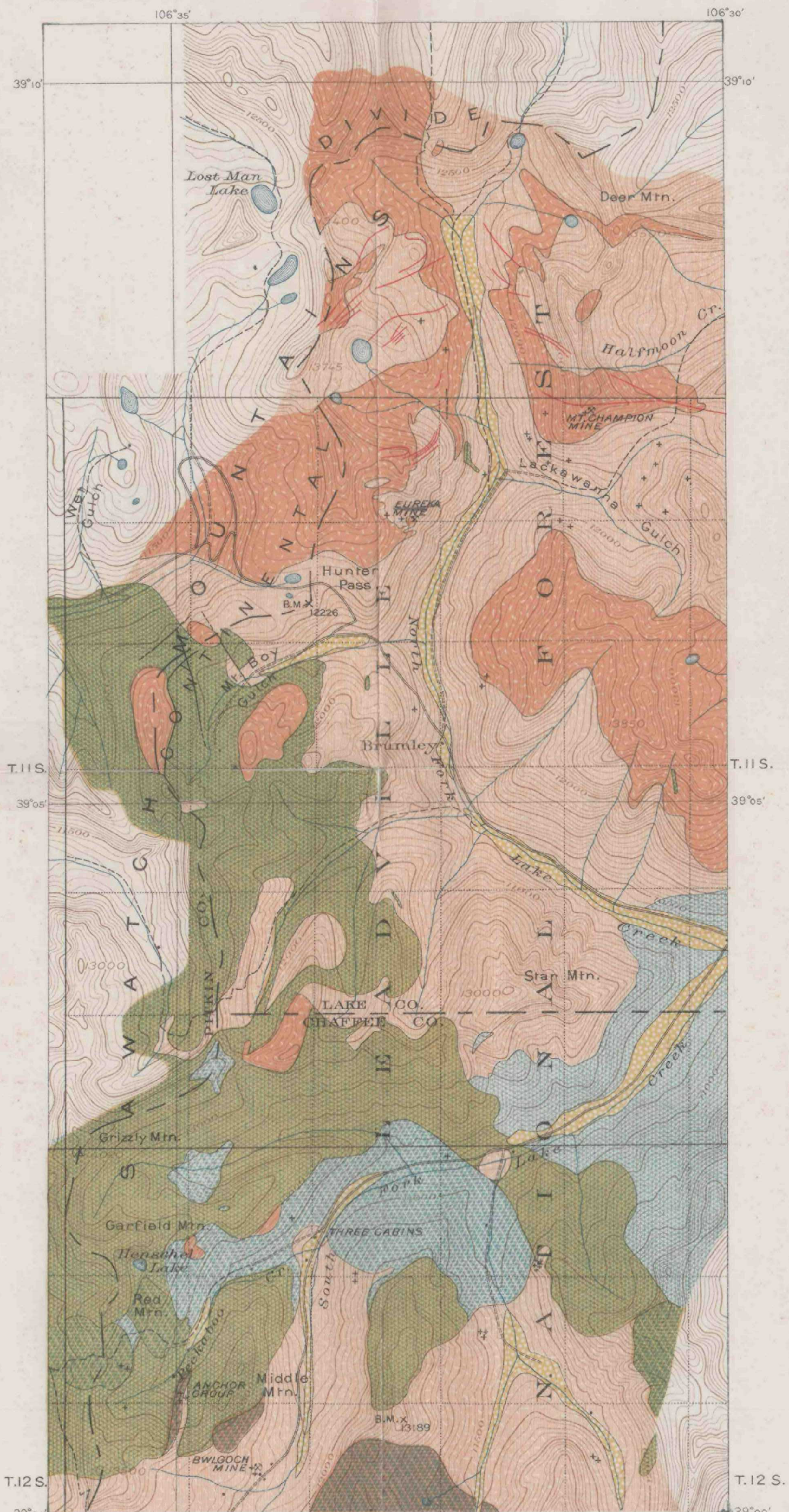
BULLETIN 19: The Cretaceous of Northeastern Colorado, Junius Henderson.

BULLETIN 20: Reports on the oil possibilities of two areas in Eastern Colorado, Norman E. Hinds and James Terry Duce.

BULLETIN 20: Report on the oil possibilities of an area in Western Colorado, R. C. Coffin.

BULLETIN 21: Ward Mining District, Boulder County, F. G. Worcester.

BULLETIN 22: A sketch of the Mineral Resources of the country adjacent to the Moffat Road. (Includes Grand, Routt, Moffat and Rio Blanco Counties.) H. A. Aurand and R. D. George.



Topography from U. S. Geological Survey
Map of Mt. Jackson Quadrangle

Geology by J. V. Howell, assisted by
J. T. Lonsdale, 1915-1916.

GEOLOGIC MAP OF THE
TWIN LAKES MINING DISTRICT, COLO.

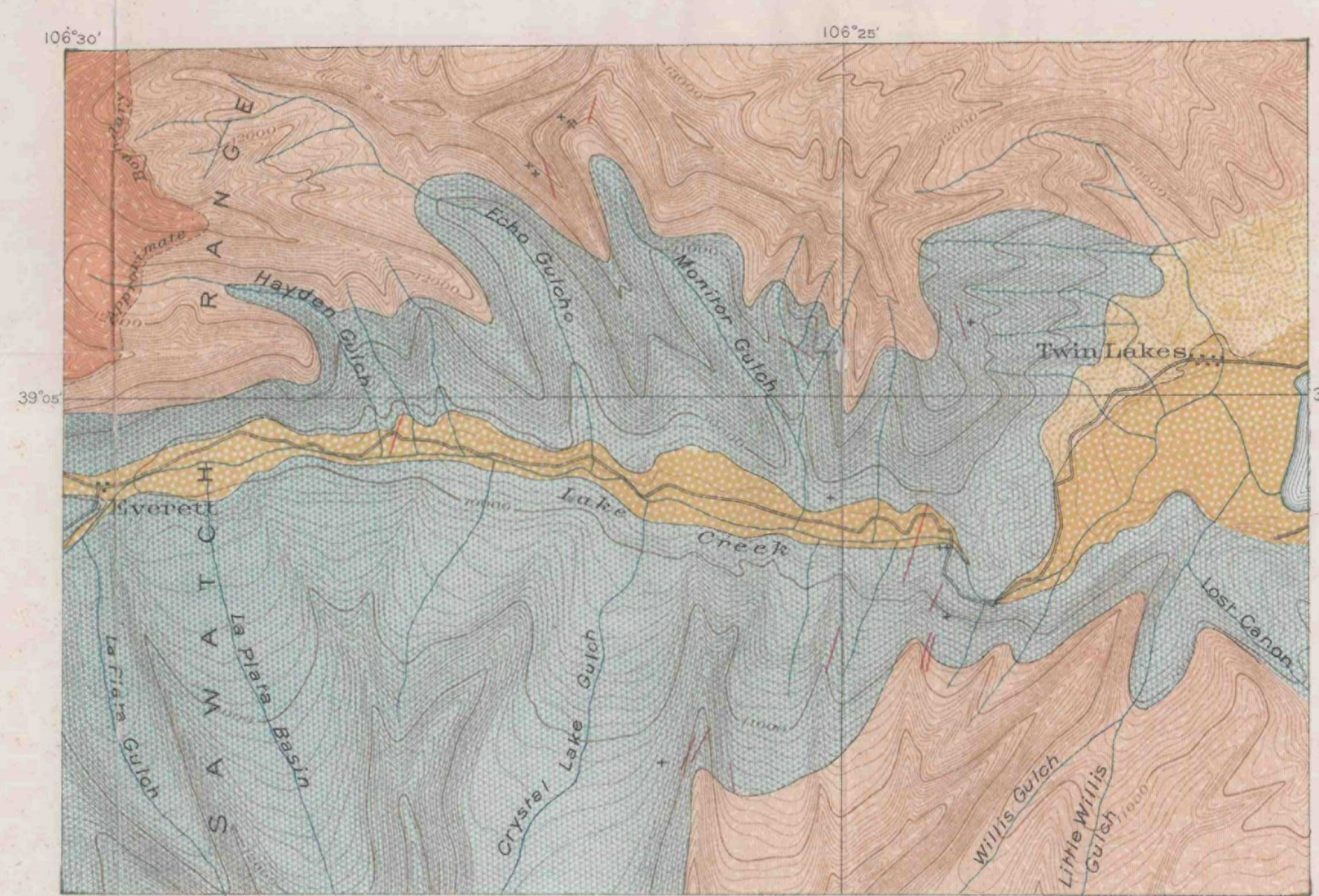
Note:—Since that part of the base taken from the Leadville sheet is inaccurate and will not match that part of the base taken from the Mt. Jackson sheet where they should join along the meridian 106° 30' the two parts of the map are shown separately.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.



Topography from U. S. Geological Survey
Reconnaissance map of Leadville Quadrangle

Geology by J. V. Howell, assisted by
J. T. Lonsdale, 1915-1916.

LEGEND

- RECENT: Alluvium
- PLEISTOCENE: Moraines
- TERTIARY: Grizzly Peak rhyolite; Red Mountain rhyolite
- LATE CRETACEOUS: Quartz porphyry dikes
- PROBABLY LATE PALEOZOIC: Hornblende diorite; Quartz diorite; Twin Lakes quartz monzonite porphyry
- PRE-CAMBRIAN: Mount Champion quartz monzonite; Gneiss-schist complex