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R. D. GEORGE, State Geologist

BULLETIN 4

GEOLOGY AND ORE DEPOSITS

OF THE

MONARCH AND TOMICHI DISTRICTS

COLORADO

BY
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LETTER OF TRANSMITTAL

State Geological Survey,
University of Colorado, December 1. 1912.

Governor John F. Shafroth, Chairman, and Members of the Advisory Board of the State Geological Survey,

GENTLEMEN—I have the honor to transmit herewith Bulletins 4 and 5 of the Colorado Geological Survey.

Very respectfully,

R. D. GEORGE,
State Geologist.

PREFATORY NOTE

After the field work of the area considered in this bulletin, was well under way, an outline of the geology was presented to the Professors of Geology of Yale University where Professor Crawford had done the required resident graduate work for the degree of Doctor of Philosophy. The Yale professors agreed that the problems involved in a correct interpretation of the geology of the region were well suited to form the basis of a thesis for the degree. The solutions of the problems undertaken, and the interpretation of the geology of the region are embodied in the present report which has been approved by the Professors of Geology of Yale University as a suitable thesis to be presented in candidacy for the degree of Doctor of Philosophy. It will be submitted to the Graduate Faculty of Yale University at a later date.

In preparing this report Professor Crawford has, at his own expense, done much work not included in the plans of the Geological Survey. This has added greatly to the value of the report, and has cost the State nothing. Among other things, several costly analyses were added, and a great deal of office and laboratory work was done to perfect the report.

R. D. GEORGE,
State Geologist.

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OF THE

MONARCH AND TOMICHI DISTRICTS, COLORADO

INTRODUCTION

FIELD AND OFFICE WORK

The topographic and geologic maps of the Monarch and Tomichi districts were made in the summers of 1909 and 1910, by a single party which spent a little more than five months in the field. The topographic mapping was done by P. G. Worcester, R. C. Coffin, R. M. Butters, and G. B. Warner. Messrs. Worcester and Coffin were engaged in this work during the greater part of the two seasons. Messrs. Butters and Warner were in the party one season each. The primary control was taken from the Hayden triangulation sheet. Mount Ouray, Hayden's station No. 1, and a sharp peak about six miles northwest of Hunts Peak are stations outside of the area mapped that were occupied. The topography along the South Arkansas was controlled by the railroad map which was tied in by triangulation. Traverse plane-tables with open-sight alidades were used in both triangulation and traverses. The elevation of points on the railroad was taken from the official railway map and profile. With these elevations for reference, other elevations were determined by means of aneroid barometers. It is too much to hope that, with the instruments used, there are no errors in the topographic map. However, the errors of triangulation were kept as low as possible by the occupation of all the high points in the area mapped, of which there are many, and by numerous intersections. It is not probable that many of the contours are in error more than two contour intervals. While the map may thus be slightly in error quantitatively, it is qualitatively accurate.

The traverses of the several topographers were combined and the complete topographic map prepared for the engraver by Mr. Worcester.

The geologic mapping closely followed the topographic mapping, and was done chiefly by the writer who was assisted a few weeks by Mr. Butters and several days by Messrs. Coffin and Worcester when time could be spared from topographic mapping. In order to get further evidence on local problems that had not been solved, to collect fossils, and to see the latest mining developments, two weeks in 1911 were spent in these districts with Mr. Warner and a week in 1912 with Mr. Butters.

Professor Junius Henderson identified the fossils collected and determined the age of the fossil-bearing strata. Mr. Butters made the assays recorded in this bulletin where not otherwise credited. The necessary drafting for the report was done chiefly by H. C. Woods and E. M. Kayden. The plans and sections of mines and sections of ore bodies are reduced from drawings made by the engineers of the mines thus represented.

ACKNOWLEDGMENTS

The field party received much valuable assistance from the resident mine owners and officers, miners, and prospectors who generously gave their time in showing mining developments. Non-resident mine owners, in their replies to inquiries have contributed a great deal that is of value. Several of the replies involved much labor, as for example, the preparation of the table, from the old records, of the output of the Madonna mine, by Mr. A. Eilers. Messrs. O. H. Aikine, F. P. Black, and H. J. van Wetering, who have made many surveys for patent, generously furnished the claim maps in their possession. The Denver & Rio Grande Railroad Company kindly provided a large-scale map and profile of the Monarch branch of the railroad. To all who have thus had a share in this work, the members of the field party are grateful.

The writer is under deep obligations to Professor L. V. Pirsson, of Yale University, for assistance in working up the petrography, for suggestions as to the general form of the report, and for criticisms; to Professors Joseph Barrell, J. D. Irving, and Charles Schuchert, of Yale University, for suggestions and criticisms; and to Professor R. D. George who, as Director of the Survey, has imposed no irksome restrictions, yet, on request, has generously given his opinion on many points. If, in this report, erroneous conclusions are drawn, the writer is alone responsible.

GEOGRAPHY OF THE MONARCH AND TOMICHI DISTRICTS

The Monarch mining district is in the southwestern part of Chaffee County, Colorado, on the east slope of the Sawatch Range whose crest forms a considerable length of the Continental Divide. The Tomichi district, in Gunnison County, joins the Monarch district on the west and is on the west slope of the range. The tract surveyed has an area of 120 square miles. That part east of the divide, 94 square miles, is all in the Monarch district excepting a small area at the head of Pomeroy and Grizzly gulches, which lies in the Chalk Creek mining district.

The Monarch district is commonly understood to extend much farther south and southeast than the limits of the accompanying maps. Little development work has been done in the unmapped area, though at Pass Creek, several miles southeast of Maysville, a small amount of gold was found, and a group of prospects south of Greens Gulch has produced a few tons of ore.

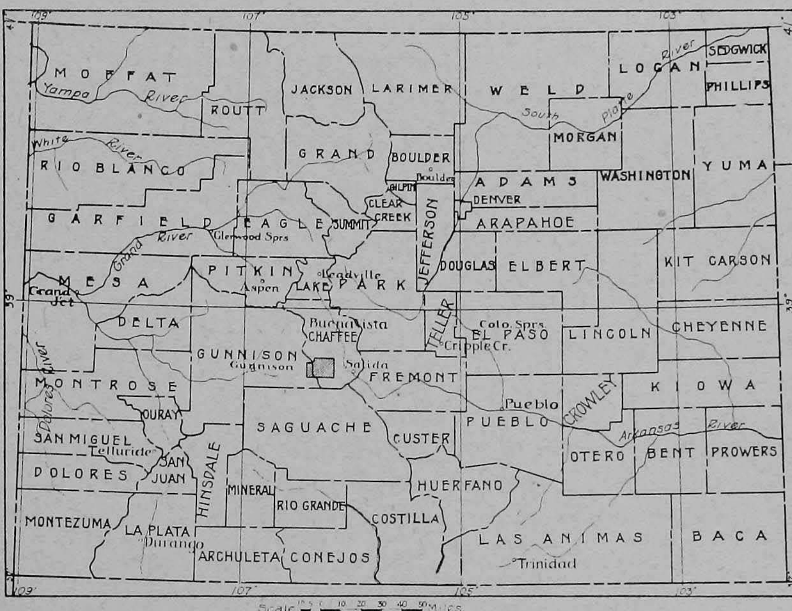

Figure 1.—Index map of Colorado, showing position of the Monarch and Tomichi districts.

The Tomichi mining district, as mapped, covers 26 square miles. This includes all the producing area of the district, although a little prospecting has been done farther west. The mineralized zone extends north into the Quartz Creek district which joins the Tomichi district along the divide at the head of Tomichi Creek. The Brittle Silver mine just north of this boundary has produced considerable high-grade ore.

The population of the two districts has been small for several years past. In the Monarch district are the permanent villages of Maysville, Garfield, and Monarch. In the summer of 1911 there were perhaps thirty people in and near Shavano, and somewhat fewer in 1910. When the North Fork valley was visited in 1912 Shavano was practically deserted. Whitepine and North Star are the only inhabited villages in the Tomichi district. The former town of Tomichi is now deserted and but few buildings remain; many were razed by a snowslide several years ago. Monarch, Garfield, and Maysville are on a branch of the Denver and Rio Grande railroad. A mixed train runs to Monarch daily from Salida which is distant about 20 miles. Garfield is also reached by tri-weekly stage, over a good wagon road, from Salida. A daily stage runs from Sargents, on the Denver and Rio Grande railroad, to Whitepine, a distance of about 12 miles. In the summer the Tomichi district is also accessible from Monarch by way of the Monarch Pass wagon road and a trail across the range north of the pass.

GEOGRAPHIC NAMES

Nearly all the geographic names used in this bulletin are local names in common use. In our preliminary report the name Syncline Hill was applied to the hill north of Monarch, and in the present report the peak capped with volcanic breccia is called Vulcan Mountain. Except a few names to designate certain faults and Paleozoic formations no other new names are proposed.

LITERATURE AND PREVIOUS GEOLOGIC WORK

The published accounts of the geology of the Monarch and Tomichi districts are few and brief. Several references to individual mines and output may be found in annual reports of the Director of the Mint; in various volumes of Mineral Resources of the United States, published by the United States Geological Survey; in the reports of the State Geologist and of the Colorado Bureau of Mines. Ore was not discovered in either district until after the work of the Hayden Survey, in Colorado, was completed, and it appears that the geologists of that organization passed over the region somewhat hurriedly. The Hayden map shows no Paleozoic sediments in the area covered by the present survey excepting a strip south of the South Arkansas near Maysville. The areal extent of the existing sediments in this locality is greatly exaggerated on the Hayden map. The pre-Pleistocene rocks are mapped chiefly as metamorphic granite with small areas of trachorheite on and near the crest of the range.

Several chapters in the Hayden reports discuss the Arkansas valley and the broader features of the Sawatch Range; these chapters are listed below. In 1885, George H. Eldridge of the United States Geological Survey, examined the Madonna mine and surroundings, but his report was not published. In 1905, Van Hise and Leith visited the iron-ore deposits near Whitepine. A geologic map of these deposits and surroundings was made by Harder and Ward in 1906. In 1908, Whitepine and other mining camps of southeastern Gunnison County were visited by J. M. Hill. The published reports of these geologists of the United States Geological Survey, with other writings which have a direct or indirect bearing on the geology of the area under consideration are listed below.

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CHAPTER I

PHYSIOGRAPHY AND QUATERNARY DEPOSITS[1]

TOPOGRAPHY

The region is one of high relief, having a vertical range of about 6,000 feet. The lowest point, at an elevation of about 8,200 feet, is on the South Arkansas, at the east border of the area mapped. Shavano Mountain reaches the greatest height, which the Hayden Survey gave as 14,239 feet. Mountains having an altitude of 13,000 feet, or more, are: Bald, Calico, Carbonate, Clover, Cyclone, Etna, Grizzly, Monumental, Pomeroy, Taylor, Van Wirt, and Vulcan, besides several which have no names known to the writer.

Since a considerable part of the region is above timber-line and without protective vegetation, many of the peaks and ridges have very steep slopes, more or less covered with sharply angular sliderock. At the east border of the Monarch district, north of the South Arkansas, the slope is gentle and grades into the nearly level uplands of the Arkansas valley. (See Pl. XVII, *A*, and topographic map.)

Though the relief of the region is high, erosion has removed a great quantity of material. The Paleozoic strata of Middle Fork and Taylor Gulch, so tilted that they escape thinning by erosion, are certainly a mile thick, and very probably 7,000 feet thick. There is no reason to doubt that most of the region was once covered by sediments having at least as great a thickness as that of the strata mentioned. Hence erosion has probably removed at least 5,000 to 7,000 feet of sediments from much of the region, besides a considerable quantity of igneous and metamorphic rocks. This does not take into account possible Mesozoic and Cenozoic rocks of which there is no record.

The topography has virtually reached the mature stage, if the effects of temporary interference with stream-work by local glaciers be excepted. Yet in the upper parts of their courses the streams have a high gradient; rapids and small waterfalls are not uncommon.

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[1] Because of the close connection between these two subjects, they are here treated in a single chapter.

STREAMS AND SPRINGS

Nearly all of the Monarch district is drained by South Arkansas River and its tributaries, of which the most important are North, Middle, and South forks. Other streams of the South Arkansas system which flow throughout the summer are: Cyclone, Jennings, and Hunkydory creeks, tributary to North Fork; Hoffman and Kangaroo creeks and Lake Fork, tributary to Middle Fork; Foose, Greens, and Lost creeks, flowing into the South Arkansas. Browns Creek, which drains a small part of the Monarch district, empties into the Arkansas River near Centerville. A part of the rainfall on the slopes northeast of Shavano Mountain finds its way to the Arkansas through Squaw Creek. Grizzly and Pomeroy creeks, heading just north of the northwest boundary of the Monarch district, are tributary to Chalk Creek, which flows, in the main, parallel to Browns Creek and also empties into Arkansas River. Tomichi Creek, which with its branches drains the Tomichi district, flows about fifteen miles southward from its source, thence west-northwest about thirty miles, and empties into Gunnison River at Gunnison. Tributaries of the Tomichi which flow throughout the summer are Canyon, Buckhorn, Fort Scott, Robbins, and Galena creeks.

While nearly all the streams mentioned are fed by surface waters from melting snows throughout almost the entire summer, many springs contribute a large volume of water throughout the year. Among the largest of these are the Monarch spring, one about half a mile east of Garfield south of the South Arkansas, the spring about three-fourths of a mile south of the saddle between Missouri Hill and Lost Mountain, and the spring at the head of Spring Creek in the Tomichi district. Here might also be mentioned the large stream which issues from the Page tunnel in Taylor Gulch. This stream does not come from a spring, strictly speaking, but from a water-course which was tapped by the tunnel.

Many of the creeks head in glacial cirques, where they are fed in the summer by melting snow. Lower in their course they flow in U-shaped valleys or canyons which have been scoured by glaciers. Marks of the moving ice may still be seen in places on the canyon walls of Browns Creek and North Fork, as high as 600 feet above the creek beds.

CLIMATE AND VEGETATION

The summers are short and cool; snow is likely to fall on the high mountains at any time. The summer snow is, of course, soon melted, but not in every summer is the heat sufficient to melt all the accumulated snow of the previous winter. There is but little uniformity in the precipitation from month to month, but the annual precipitation is generally considerable.

District Forecaster F. H. Brandenburg of the Denver forecast district, has kindly furnished the record, kept by the United States Department of Agriculture Weather Bureau, of the precipitation at Garfield for the years of 1910 and 1911, and at Marshall Pass from 1900 to 1911, inclusive. The annual precipitation at Garfield in 1910 and 1911 was 17.61 inches and 26.31 inches, respectively. In 1910 the greatest precipitation for one month was 2.33 inches, in February. In 1911 the greatest precipitation in a single month was 4.63 inches, in July. At Marshall Pass the precipitation in July, 1911, was 5.98 inches. The precipitation at Marshall Pass for the year 1911 was 18.70 inches.

The soil in the alluvial valley bottoms near and below Maysville and just south of the south border of the mapped area in the Tomichi district is fertile and produces good crops of hay, grain, and vegetables. Small fruits and, at times, apples are successfully grown in the South Arkansas valley. Although good native grass grows both above and below timber-line in many parts of the region, there are many barren tracts.

Formerly pine, spruce, and fir covered most of the high slopes below timber-line, but much of the timber has been removed. A few restricted areas—such as parts of the valleys of Browns Creek, North Fork, and Middle Fork—are still densely forested; but the renewal of a demand for timber, such as existed in the eighties, would soon exhaust the supply in the immediate vicinity of the mines.

GLACIATED AREAS

Not only in the districts surveyed, but also both north and south of these districts, glacial cirques are common near the crest of the Sawatch Range. In the mapped area most of the valleys heading near the Continental Divide, and a few heading on the slopes of high mountains some distance from the divide, have been glaciated.

Local glaciers heading, respectively, near Agate Pass south of Monarch, south of Bald Mountain, south of Clover Mountain, on Chalk Creek Pass, at the head of Hoffman Park, on the south slope of Taylor Mountain, and near the source of Foose Creek, united to form one of the largest glaciers of the Monarch district. This glacier was joined at Maysville by another large glacier formed by the several branches heading, respectively, in Hunkydory Gulch, north-northwest of Mount Etna, near Pomeroy Mountain, near Grizzly Mountain, and in Jennings Gulch. The course of another large glacier can be traced in Browns Gulch from the slope of Cyclone Mountain to the mouth of the canyon and perhaps farther. Small glaciers existed in the valley of Squaw Creek, on the southeast slope of Shavano Mountain, and at Cree Camp.

The former glaciers of the Tomichi district cannot be so easily traced. There are, however, evidences of glaciation from Tomichi Pass and the slopes of Granite Mountain along the Tomichi valley as far as it has been mapped. That the glacier which moved down this valley was of considerable thickness and extent is shown by the presence of numerous boulders of the Etna porphyry high on the slopes south of Whitepine. Traces of a glacier may also be seen near the source of Canyon Creek. In the Chalk Creek district, Grizzly, Pomeroy, and Chalk Creek gulches have been glaciated in their upper part.

EFFECTS OF GLACIERS

The glaciers mentioned have been important as a physiographic and geologic agent in four ways, namely: (1) in planing down and reducing irregularities of surface; (2) in gouging out rock basins, thus increasing the surface irregularities; (3) in forming morainal lakes and rough-and-tumble morainal topography; and (4) in the formation of the high terraces, which are designated fluvio-glacial on the geologic map which accompanies this bulletin.

PLANATION

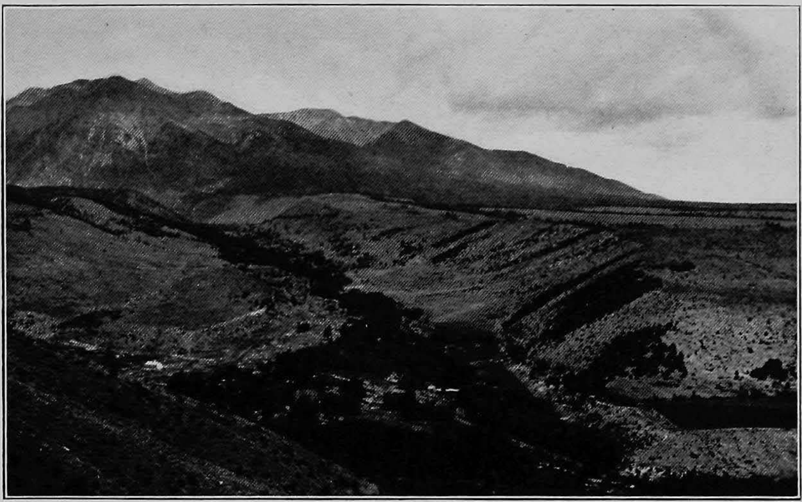
Results of glacial planation may be seen in nearly all the cirques and valleys in which the glaciers moved. In most places the originally polished surface has been dulled by weathering and rarely retains glacial striæ. Under these conditions the effect of former glaciers is seen principally in the rounded or planed surface of the rocks. Good examples of glacially rounded forms, roches moutonnées, are found near the creek in the granite area east of Garfield. But glacial abrasion has not been confined to the bottom of the moving ice-mass. Locally in Browns Gulch and North Fork the canyon walls at least 600 feet above the stream-bed are so smoothed that the sunlight is conspicuously reflected from them. Since the canyons were without doubt materially deepened by glacial erosion, it is not known that this abrasion was effected synchronously with that of the present bottoms of the canyons. Nevertheless, the high terraces described farther on indicate that the glaciers were several hundred feet thick.

In a very few known localities in the valley bottoms, where soil or debris has evidently overlain the glaciated rocks, striations and a beautiful polish have been preserved. One of these examples may be seen in the North Fork valley below Shavano, where soil was removed when the wagon road was made or repaired. Larger visible areas in which the rock surface still retains an excellent polish are found in the granite and granite porphyry exposures south of Browns Creek.

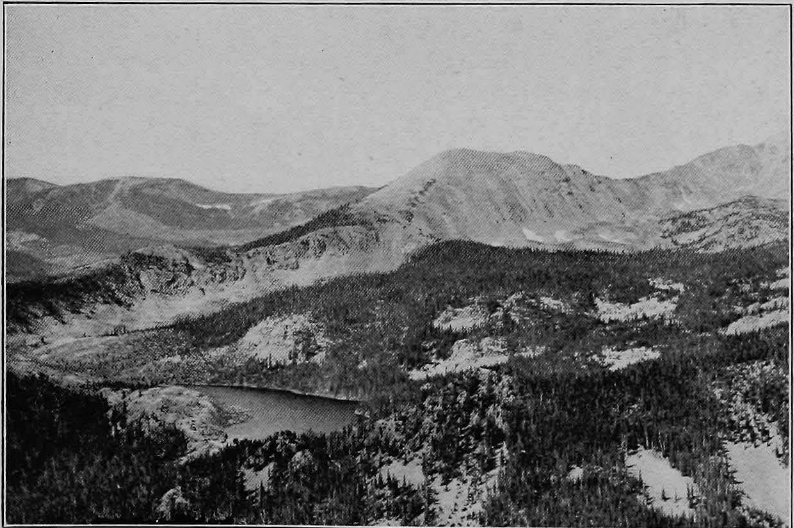
ROCK BASINS

One of the best examples of glacial gouging in this region is the rock basin occupied by Boss Lake (Pl. VI). The granite surface extending from the lake to the crest of the range, though glaciated, probably did not suffer great reduction. The low ridge east of the lake and the outlet were severely abraded, although the rock, having been metamorphosed, is very resistant. Yet the weight of ice per unit of area, owing to the eastward-narrowing of the channel, was sufficient to make the glacier here a powerful agent of erosion. While the depth of the water has been increased by an artificial dam, the natural depression is much below the level of the surrounding walls. Glacial gouging was unusually effective here, perhaps because of mineralization along the fault which underlies the lake. The postulation of any considerable body of mineral under water, where its existence or nonexistence can be proved only with difficulty, if at all, may provoke incredulity, or even a smile, on the part of the reader; yet the supposition is supported by the evidence of much iron sulphide east and north of the lake, as well as much magnetite and a little galena just east of the lake.

Other lakes and lakelets whose basins were gouged out by glaciers are to be seen near the source of Chalk, Pomeroy, and Grizzly creeks and North Fork, as well as near the crest of the range west of Monarch and west of Boss Lake. These basins are



A.—HIGH TERRACES BORDERING NORTH FORK ABOVE MAYSVILLE
Shows also a low terrace west of creek. Sharp peak in background is Shavano Mountain.



B.—BOSS LAKE
The lake occupies a rock basin formed by glacial gouging.

generally shallow, but the depth of several of them is increased by morainal damming at the outlet side. Thus nearly every lake and lakelet in the region owes its origin to glacial action.

MORAINES

Moraines are very common in the region under consideration, but each covers only a small area. Those greatest in areal extent are shown on the accompanying geologic map. Most of the smaller ones, as well as those which are so thin that they do not cover the bedrock continuously, and those which border the creeks in valleys where the kind of bedrock underlying the moraines is ascertainable from the surroundings with a reasonable degree of certainty, are not represented on the map. These could be shown only at the cost of much time in the field, and would add little or nothing to the value of the map for the intended purposes.

In general, the moraines are probably of comparatively slight thickness. Many have been crossed by prospect shafts fifteen to thirty feet deep. The greatest known thickness is found just west of Monarch, where the moraine is fifty-six feet thick, as determined in a shaft sunk by the Monarch Contact Mining, Milling & Development Company.

The surface of the moraines is very uneven; a few depressions are so deep as to hold water permanently. As examples of morainal lakelets, those below Cree Camp may be mentioned. The morainal material is largely made up of subangular boulders of nearly all the igneous rocks of the region. Finer material, while generally present, is not conspicuous at the surface of most of the moraines. Locally, as in the valleys of Middle and Lake forks, there has accumulated, on the morainal surface, considerable soil, which supports a heavy growth of timber.

Among the largest moraines are those, respectively, in the vicinity of Monarch, in Middle Fork and Lake Fork valleys, along the creek below Cree Camp, in the canyon of North Fork, east of Shavano Mountain, and on both sides of Foose Gulch. Most of the moraines are in valleys, but a few occupy ridges or high slopes. Perhaps the best example of a moraine-covered ridge is that south of Foose Gulch. West of Foose Gulch are large morainal patches on the steep slope several hundred feet above the creek-bed. The small ridge about 700 feet above the creek-bed and one-quarter of a mile northeast of Garfield is capped by morainal material. This is probably a lateral moraine, deposited by the glacier which moved down the South Arkansas valley. At nearly the same elevation, about four-fifths of a mile south, is the conspicuous lateral moraine doubtless deposited by the glacier just mentioned. In the Tomichi district, glacial boulders, evidently from Monumental Mountain, are found on the slopes south of Whitepine, at an elevation of several hundred feet above the creek-bed.

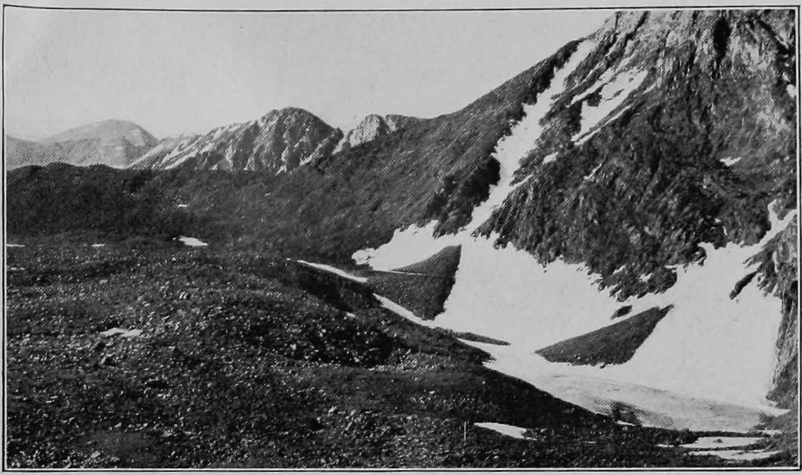
FLUVIO-GLACIAL DEPOSITS

HIGH TERRACES

Both north and south of the South Arkansas are deposits which form high terraces, having a very uniform and gentle slope, except where they are dissected by erosion. These deposits extend toward the north many miles on the west side of Arkansas River, and are designated on the Hayden map in large part as scattered drift, but in part as moraines. Of the drift Endlich[1] says:

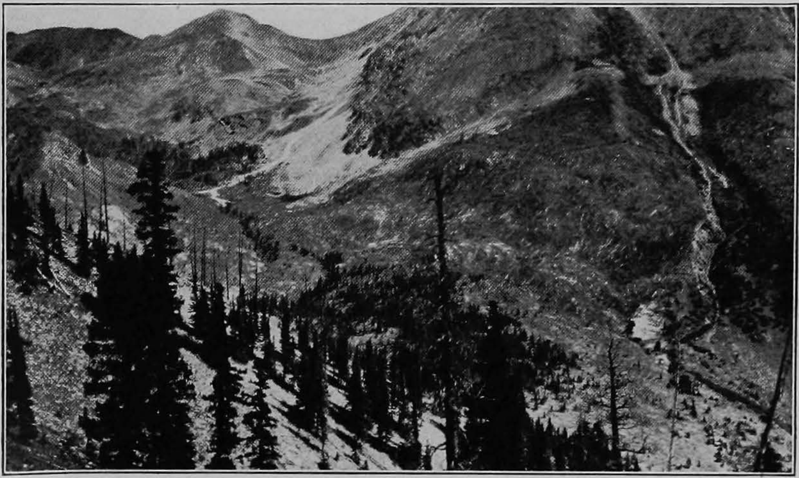
> Drift covers a considerable area along the western side of the Arkansas. A belt of about five miles in width runs along it, keeping parallel in its course and narrowing out toward the south. This drift is composed, so far as I have been able to learn from examinations at certain comparatively isolated points, of material that was brought down by the river mainly; secondarily, by the different creeks striking the river from the west. Although glacial action seems to have had considerable effect in transporting drift-material higher up on the Arkansas, I have not recognized any such means of conveyance in that portion of our district. Taking into account the shifting of streams parallel to their own general course, it becomes evident that the material deposited immediately along the base of the range parallel to the river must have been deposited by it, and not by any other means, provided lithological identification of the drift-rocks admits of no contradiction. This latter does not seem to be the case, however, and the accumulation of the greater portion of the redeposited material I ascribe to the action of the Arkansas. A number of creeks running out from deeply cut ravines in the mountains have cut in an almost straight line through the drift; a circumstance which is readily explained by the fact that its resistance was so small as to necessitate no considerable deviation from a straight line. As they have cut in deeply, however, forms strongly resembling moraines have not infrequently resulted, which might mislead. Opposite station 4, the canyon of the Arkansas narrows and the drift-deposit disappears.

[1] Endlich, F. M., Ann. Rept. of the U. S. Geol. and Geog. Survey of the Terr., 1874, p. 346.



A.—WATER PONDED BY TALUS NEAR POMEROY PASS

Talus, rolling down over snow-bank, has accumulated some distance from foot of cliff. Photographed at distance of one-fourth mile from center of lakelet.



B.—LANDSLIDE TOPOGRAPHY NORTH OF TOMICHI

Though Hayden[1] believed that a great glacier once occupied the Arkansas valley, he thought that the surficial deposits were laid down in a lake. He says:

The Arkansas valley, from its head in Tennessee Pass to the point where the river cuts through Front Range and opens out into the plains, has been worn out of the granite mass to a great extent. The valley is partly a fissure, but is mostly due to erosion. The drainage was undoubtedly started by the fissures produced by the great uplift, but, as broad and deep as it is, it is undoubtedly due mostly to erosion, and by this illustration we may form some conception of the work of this powerful agent in giving form to the surface of this mountain region. From the crest of the Park Range across the Arkansas valley to the crest of the Sawatch the distance will average from ten to fifteen miles, in a straight line, and the average elevation above the water-level of the Arkansas River must be about 1,500 feet. Now, it is probable that three-fourths of this vast space from the Tennessee Pass to the Poncho Pass, near the head of San Luis valley, a distance of one hundred miles, has been worn out by erosion, and the greater portion of the material carried down the river and distributed over the plains. It is probable, also, that this great space was at no very ancient period filled with one vast glacier, which doubtless performed the greater part of the grinding-up of the rocks and the wearing-out of the valley. The glacier-worn sides of the mountains on either side of the valley extending nearly to the summits, the remarkable morainal deposits in the main valley and on the sides of the gorges point strongly to that conclusion. We hope in the succeeding chapter to describe more in detail the phenomena of ancient glacial action, which is so admirably shown on both sides of the Sawatch Range. * * *

In the lower portion of the Upper Arkansas I described, in my annual report for 1869, a group of light-colored marls, 800 to 1,200 feet in thickness, under the name of Arkansas marls. I then regarded them as of Pliocene age, and noted their inclination as 3° to 5°, which would imply that they were deposited before the great Sawatch Range had reached its present height. It is plain that at a period comparatively modern in date there was a lake here at least forty or fifty miles in length, and from five to ten in breadth, and that in the lower portions several hundred feet in thickness of fine sediment were deposited in moderately quiet waters. The numerous little streams that flow from the Sawatch Range toward the Arkansas cut deep channels through this modern deposit. The quantity of rounded boulders of various sizes in the vicinity of these streams is immense. Even after the lake waters had passed down the Lower Arkansas, through the canyon, there must have been tremendous glacial as well as aqueous forces operating from the deep gorges in the mountains, transporting a vast amount of drift material into the valley. Just how much of this broad expansion is due to erosion it is difficult to determine, but I am inclined to the belief that there was originally only the fracture of elevation, and that the old lake-basin is mainly due to erosion. On neither side of the valley do we see any of the older sedimentary rocks. From

[1]Ann. Rept. of the U. S. Geol. and Geog. Survey of the Terr., 1874, pp. 48, 49

Poncho Pass to the very source of the Arkansas, a distance of eighty miles, no rocks but Igneous and Metamorphic can be seen upon the east side.

The high terraces along the Arkansas in the Leadville region have been studied by Capps and Leffingwell[1] and by Westgate.[2] These geologists, who state that the character and arrangement of the material in the terraces examined can be determined, ascribe the deposition of the terraces to streams fed by glaciers.

Within the mapped area of the Monarch district the topography of the high terraces and their relation to the principal valleys furnish the chief data from which the origin of the terraces may be inferred. There are no good outcrops, the surface being covered with soil or wash, and on the terraces there are no mine or prospect shafts with standing walls. However, on the east side of North Fork a washout under a broken flume has laid bare the terrace rock without disclosing its arrangement. There has been much creep of the material in the exposure and consequently a disarrangement of any bedding that may have existed. Here are a great many boulders, mixed with pebbles, sand, and clay. The boulders range in size from a few inches to three feet, and include all the varieties of rock found in the canyon above. No marked faceting could be found. This exposure is below the middle of the terrace, which at this point is about 500 feet high. That large boulders are common near the top of the terraces is evident from the numerous boulders thrown out of shallow prospect holes west of North Fork.

Two exposures of undisturbed terrace deposits outside of the mapped area were seen by the writer. The first is near the mouth of Greens Gulch, where a section nearly 200 feet thick is exposed. The deposits are chiefly sand, pebbles, and boulders, and show considerable assortment. Sand exceeds the boulders in quantity. It is more or less distinctly stratified and contains lenticular masses of boulders. Many of the boulders are waterworn. The second observed exposure is east of Mount Princeton, beside the wagon-road, where the material is chiefly an aggregate of angular to subangular boulders of quartz monzonite much decayed. No marked assortment was observed here.

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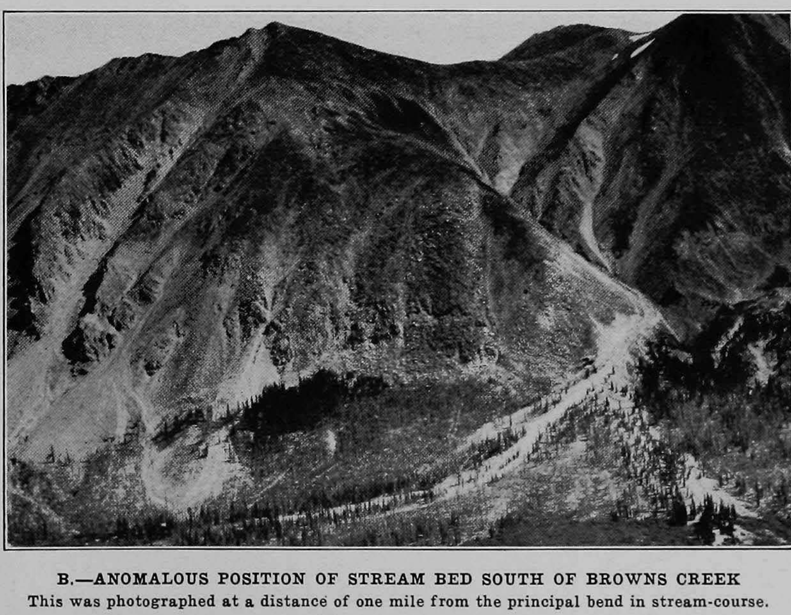
[1] Capps, S. R., and Leffingwell, E. D. K., Pleistocene geology of the Sawatch Range, near Leadville, Colorado: Jour. Geology, vol. 12, 1904, pp. 698-706.

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

[2] Westgate, L. G., The Twin Lakes glaciated area, Colorado: Jour. Geology, vol. 13, 1905, pp. 285-312.

A.—SLIDEROCK ON CALICO MOUNTAIN



B.—ANOMALOUS POSITION OF STREAM BED SOUTH OF BROWNS CREEK

This was photographed at a distance of one mile from the principal bend in stream-course.

Plates VI and XVII and the accompanying topographic map, show the character of the terrace topography. The terraces reach a height of 500 or 600 feet above the bottom of the adjacent valleys. The pronounced ridge just east of North Fork is evident at a glance at the topographic map and Plate VI. The form of this terrace is very different from that of most stream terraces, which commonly are level or slope toward the valley. The profile strongly suggests the deposition of the material from streams flowing outward from the melting border of the glacier which occupied the valley, and whose top was higher than the present terrace. It is not probable that deposition of the large boulders with much fine sediments would take place from ordinary streams. A subsequent melting of the glacier would result in the deposition of the morainal boulders in the valley. Since there is no evidence of a material deepening of the valley by stream erosion after the terraces were deposited, it is assumed that the valley itself was formed in pre-glacial and glacial times. Glaciers of other valleys doubtlessly contributed a large share to the terraces as a whole, and it is probable that a large proportion of the material was furnished by the Arkansas River itself during the Glacial period.

In mapping it was difficult to distinguish between the moraines and high-terrace deposits near the upper limits of the latter, and it is very probable that the terrace deposits are bordered by moraines even where not so indicated on the map. Certain it is that there seems to be a fringe of moraines along the upper border of the terrace deposits south of the South Arkansas.

LOW TERRACES

Low terraces are found north of the South Arkansas about two miles east of Garfield, north of the same stream east of Maysville, and west of North Fork at Maysville. (See Pl. VI.) These terraces, which are perhaps not over 100 feet above the adjacent valleys, are several hundred feet below the high terraces described. Except in elevation, the low terraces are very similar to the high terraces in appearance. There are no exposures in which the assortment, or lack of assortment, of the material forming these terraces can be determined. While the relation of the low to the high terraces remotely resembles that which may exist between stream terraces, there is at hand no convincing evidence that the main streams have appreciably deepened their valleys since the region was glaciated.

From the recorded observations, taken with the conclusions of geologists that there have been two or more epochs of glaciation in Colorado, it is inferred that the low terraces were probably deposited at the edge of smaller glaciers during an epoch of glaciation later than that in which the high terraces were formed. The age of either kind of terrace relative to the moraines on the higher slopes was not determined.

EFFECT OF SNOW

Near the foot of several cliffs are accumulations of loose rock, which have apparently been deposited at the front of large banks of snow or ice. A few of these accumulations reach a height of many feet and have ponded sufficient water to form lakelets fifty feet or more in diameter. One of the largest lakelets probably of such origin is northeast of Bald Mountain. Plate VII shows a smaller one southeast of Pomeroy Pass.

In early summer large blocks, which have been detached from cliffs, and which finally come to rest some distance from the foot of the cliff, may sometimes be seen rolling or slowly moving down over a bank of snow. In this high altitude, where snow remains nearly all the year, the rock masses so accumulated during many years, even centuries, must be considerable. The disappearance of the snow during the short summers leaves depressions like those described. Some of the lakelets—as, for example, one about a mile south of Bald Mountain—owe their origin apparently to the combined effects of glacial gouging and the damming by boulders deposited at the front of a snowbank.

LANDSLIDES

Typical landslides are not common in the Monarch and Tomichi districts. The largest landslide in the mapped area is about a mile north of Tomichi. Here large masses of the country rock, chiefly granite and breccia, have slid down toward the southwest from the lower part of the slope of Monumental Mountain and southward from the south shoulder of Central Mountain. From the mouth of Fort Scott Creek northward about half a mile the rocks in mass are mixed in great confusion without pronounced breaking, while the surface presents the hummocky character typical of landslide topography (Pl. VII).

On Monarch Hill, a short distance south of the entrance to the Madonna No. 6 tunnel, is a mass of the siliceous shaly stratum of the Ouray formation normally found at the base of the Ouray. This stratum carries a layer of quartzite, and,

MOUNT ETNA

Vertical range, 1,300 feet; horizontal range, nearly 6,000 feet. Talus has traveled about a mile and a quarter.

strangely enough, has lodged almost directly above the "parting quartzite" cut by the tunnel. The thinness of the quartzite bed at the surface and the difference in dip and strike from that underground, together with the presence of the chocolate-colored shale at the surface, prove that the exposed rock has come from a higher position.

The hill at Cree Camp presents an appearance of having been formed by a landslide from the slope of Taylor Mountain, but the evidence at hand is not convincing enough to warrant a positive statement.

TALUS AND TALUS CONES

Sliderock, composed of angular fragments from a few inches to many feet in diameter, is very common on most of the steep slopes. Most of this material has doubtless accumulated gradually, though there have probably been individual slides of considerable mass. Calico and Cyclone mountains present good examples of sliderock-covered slopes (Pl. VIII). Many of the masses of sliderock are scores of feet thick.

A remarkable phenomenon resulting apparently in part from sliderock, or perhaps more properly a rockslide, was observed about a mile north-northwest of Shavano Mountain, and deserves special mention. Here a stream-course hugs the slope of the mountain, having left the ravine below. This anomalous condition is shown (Pl. VIII, *B*) in the photograph taken at a distance of about a mile. The height of the present stream-bed above the bottom of the original channel was not measured, but it is probably not less than 100 feet. The former course, which was near the contact between granite on the east and quartz monzonite on the west, tended to work westward, probably on account of the greater resistance of the granite. A steep cliff of quartz monzonite was thus formed, and has furnished much debris which has partly filled the channel. This debris, added to the result of partial unloading of the stream, owing to an abrupt change in gradient, has apparently forced the stream to turn from its former course. Below this point for a considerable distance erosion has exceeded deposition. It is possible, also, that snow and ice, filling the ravine at some former time, may have been melted along the east border sufficiently to furnish for storm waters a channel which, once occupied, became the permanent channel for the stream.

One of the most conspicuous talus deposits of the region is on the south slope of Mount Etna, where it may be seen from a distance of many miles as a white streak in contrast with the darker weathered rock on each side. This talus and also a talus cone at the foot of the mountain are shown in Plate IX. Only comparatively small blocks hang on the steep slope near the top of the mountain, while the cone below contains a great proportion of boulders several feet across. The vertical height of the cone is 300 or 400 feet, while the slope of the surface of the lower part of the cone is about 25°. The boulders at the foot of the slope have passed through a horizontal distance of nearly 6,000 feet and a vertical distance of about 3,000 feet. They have, therefore, rolled about a mile and a quarter before coming to rest. The momentum gained by a large boulder at the steep upper part of the slope is evidently sufficient to carry it to the base, even over a slope of low angle in the lower part of the course.

That snow or water has not been an important factor in the transportation of the boulders is shown by the assortment of material (Pl. X). The largest blocks are at the foot and the smallest at the top of the cone; whereas, if they had been transported by water, the largest blocks would have been dropped first, while, if they had been brought down by snowslides, there would be no marked assortment. However, snowslides have passed over this talus, as shown by the removal of the timber on both sides of the creek at the foot of the slope.

Talus cones are not uncommon in other parts of the region, particularly in Browns and North Fork canyons. (See Pls. VII and VIII.)

TALUS GLACIERS

The most typical talus glacier, or rock-stream, in this region is found about a mile and a half northwest of Shavano Mountain, and is shown in Plate X. Part of the talus at the foot of Calico Mountain also has some of the features of a talus glacier. In the area mapped the structural conditions favorable to the formation of large talus glaciers seem to be generally lacking. According to Chamberlain and Salisbury[1], their development probably includes: "(1) the passage of the talus over snow-banks at the bases of cliffs, (2) sliding, creeping, and slumping of bodies of talus, perhaps both when bound together by ice and when not so cemented, and (3) incipient glacial motion."

[1] Geology, vol. 3, p. 474.

A.—TALUS CONE AT FOOT OF MOUNT ETNA
This is a near view of the lower part of the cone shown in Plate IX.

B.—TALUS GLACIER SOUTH OF BROWNS CREEK

ALLUVIUM

In general, the streams have a high gradient and have deposited but little alluvium in their valleys. In the South Arkansas valley, however, at and above Maysville, there is a strip of alluvium wide enough to permit of the cultivation of small fields. East of Maysville the alluvial bottom-lands widen sufficiently to make room for many large farms. In Foose Gulch and in Monarch Park south of Monarch are local alluvial deposits which may have been laid down during an epoch of glaciation or soon afterward.

In mapping, it was found impracticable to separate the alluvium, ice deposits, and some debris in the Tomichi district. Accordingly they are all represented on the geologic map in one pattern. Much of this is typical alluvium, especially that in the Tomichi valley. In the same valley, below the area mapped, for several miles down, the alluvial bottom-lands have an average width of probably half a mile or more. This valley is occupied by several successful ranchers, whose principal crop is hay.

Alluvial fans.—Small alluvial fans are numerous in several valleys. Perhaps the largest and most typical are in Greens Gulch and the valley of North Fork above Maysville. Here storm waters have washed down the unconsolidated material of the high terraces, through gullies and ravines. Numerous alluvial fans are thus formed at the foot of the terraces. A good example above Maysville is indistinctly shown in Plate VI, *A*, just below the center of the photograph. The alluvial fans are represented on the map with the same patterns as the creek-deposited alluvium.

SOIL

Fertile soil has been developed on most of the creek-deposited alluvium, and more or less has accumulated on the high terraces and moraines. Even the bottoms of most of the ice-scraped cirques have a thin covering of soil, in which grows thick-set but rather short grass during the few weeks of summer when it is not covered by snow.

In a few places where drainage is poor are found bogs many feet deep. These bogs contain a large proportion of roots of grass and willows in a condition of greater or less decay, the whole mass being constantly water-filled. The best examples of bogs are found in Browns Gulch and above Shavano in the valley of North Fork.

CHAPTER II

OUTLINE OF GEOLOGIC HISTORY[1]

The pre-Cambrian history of the region is obscure. It is evident, however, that long before the deposition of the oldest existing Paleozoic sediments the region was subjected to profound metamorphism by which the sedimentary rocks and probable igneous rocks then present were changed to quartzite, schists and gneisses. Either synchronously with the regional metamorphism or, more probably, later, these ancient rocks were invaded by a granite batholith which is now exposed over a large area.

This granite and the ancient metamorphic rocks were subequently so long exposed to erosion that a comparatively low relief, if not a peneplain, was developed. This erosion probably began in pre-Cambrian time and closed with early Saratogan (Upper Cambrian). This long period of erosion may or may not have been interrupted by short epochs of sedimentation.

In late Cambrian time the sea advanced over the region when the water-worn quartz sand of the Sawatch quartzite was deposited in shallow water. It is unknown how long sedimentation continued. After a later emergence the region was exposed to erosion long enough for the removal of nearly all the sediments.

When the sea again advanced, probably in Middle Ordovician time, the shore-line apparently did not remain long in the vicinity, as shown by the fact that the limestone deposited during this submergence rests directly on the quartzite and granite or is separated from them by at most two or three inches of shaly material. Nowhere within the area mapped is there sandstone or quartzite below the limestone other than remnants of the Sawatch quartzite. If such sediments were deposited near the shore as it advanced over the land, they were removed by currents before the deposition of the Ordovician limestone.

Throughout the time when the greater part of the Ordovician limestone was being laid down the relief of the adjacent land mass must have been low, since mechanical sediments are almost

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[1] Except the brief summary, in the last paragraph of this chapter, of Quaternary physiographic processes, the statements here made are based on observations recorded in detail in following chapters.

negligible in amount. The submerged area remained at moderate depth long enough for the accumulation of about 250 feet, or more, of limestone. After a probable temporary shoaling, when a sandy stratum was deposited, there was apparently an emergence and a removal by erosion of part of the limestone. An advance of the sea and shallow water furnished the essential conditions for the deposition of the "parting quartzite." The thickness of the quartzite varies greatly, but gradually, indicating a difference in the amount of sediments from place to place or an erosion interval after they were deposited. Conditions favorable for the deposition of the highest member of the Ordovician limestone were much like those when the lowest member was deposited, namely, a period of quiet, clear water and considerable removal from the shore.

Between the formation of the limestone in probably late Middle Ordovician time and the formation of the Upper Devonian Ouray limestone there is a lost interval in so far as the fauna is concerned. The sediments between the highest determined Ordovician horizon and lowest determined Devonian horizon are less than 150 feet thick. About half of this thickness, by the variability in character, records several changes in conditions of sedimentation. It is probable that after the deposition of the known Ordovician and prior to the deposition of the known Devonian the land had a low relief and degradation was slow. The area under consideration was probably slightly above sea-level during a great part of the time for which there is no faunal record, including probably Upper Ordovician, the Silurian, Lower Devonian, and Middle Devonian. During much of this time[1] the area may have been below sea-level, receiving sediments slowly derived from a base-leveled land area. It is not impossible that during this long period there were several oscillations of the strand-line by which the region was alternately submerged and exposed.

Accumulation of sediments was apparently continuous from the beginning of Ouray time until its close, but was possibly, if not probably, interrupted by an emergence and erosion interval immediately before the black dolomite of Mississippian time was laid down. If dolomitization be disregarded, the entire formation, excepting a few feet near the top, was deposited under nearly

[1]Blackwelder, Eliot, The valuation of unconformities: Jour. Geology, vol. 17, 1909, pp. 289-299.

Barrell, Joseph, Am. Jour. Sci., 4th ser., vol. 29, 1910, p. 554.

uniform conditions of clear and only moderately deep water. Near the close of this sedimentation period, conditions became favorable for the deposition of mechanical sediments. It is unknown how long sedimentation continued after the deposition of the Ouray formation. Through at least the later part of the Mississippian period the region was again a land area.

When the sea again transgressed the land in Upper Carboniferous time, a great thickness of mechanical sediments, chiefly shales and sandstones, was deposited. Only a comparatively few strata of limestone, about 800 feet above the base of the Garfield formation, indicate clear water of a quiet sea. Land erosion of an adjacent land mass was active during almost the entire period of Garfield sedimentation, when nearly 3,000 feet of shales and sandstones accumulated on the sea bottom which was sinking relatively to the adjacent land. The large proportion of shales indicates that the local waters were muddy during much of this time.

No evidence is at hand which proves that a long erosion interval succeeded the deposition of the Garfield formation. However, the succeeding sediments of the Kangaroo formation are mainly shallow water or fluviatile deposits. Some of these, particularly the arkosic strata, indicate a rapid transgression of the sea over a land area on which had accumulated rock debris formed chiefly by disintegration, with a minimum of decay. The Kangaroo epoch of rapid sedimentation may have been interrupted by one or more erosion intervals.

There is no known record of the Mesozoic era in the region. It is not impossible that sedimentation was going on during part of the era. The nearest described Mesozoic rocks are the Jurassic and Cretaceous beds of the Anthracite-Crested Butte region.[1] Subsequent to the deposition of the youngest consolidated sediments the region was subjected to strong compressive forces which threw the strata into a series of anticlines and synclines. The folding was accompanied by much faulting.

Evidently after the strata were tilted and probably in Tertiary time, much of the region now occupied by the Sawatch Range, was invaded by a large batholith of quartz monzonite whose southern limits are within the area mapped. The batholithic invasion was preceded and followed by intrusions of granular rocks in stocks. Minor intrusions of porphyry also succeeded the

[1] Folio 9, U. S. Geol. Survey.

batholithic intrusion. It is probable that some of these minor intrusions took place long after the initial post-Carboniferous plutonic intrusion. A small part of the Sawatch Range was the seat of explosive volcanic disturbance near or at the end of the general period of igneous activity.

In all probability most of the primary ore minerals were formed immediately after and as a consequence of the intrusion of quartz monzonite. Oxidation of the ores began later and has continued to the present.

Subsequent to the period of igneous activity, and probably in part synchronously with that period, erosive agencies have been active in removing a great amount of rock and shaping the present topography. Probably in Pleistocene and in more recent time local glaciers were an important factor both in erosion and in the deposition of surficial rocks. Recent time has been characterized chiefly by landslides and the work of running water.

CHAPTER III

PRE-CAMBRIAN ROCKS

Rocks older than the oldest Paleozoic sediments of the district are exposed in the east, south, and west parts of the region surveyed, and extend far toward the south. They comprise gneisses, schists, granites, pegmatite, and a little quartzite. A few dikes of diorite and syenite in the granite area are also probably of pre-Cambrian age.

GNEISSES AND SCHISTS

These rocks are confined to the east and southeast parts of the area mapped. They differ greatly in character and often show sharp contrasts in the composition of alternating or successive bands. Individual bands may have a thickness of a few inches to many feet. The strike of the foliation varies widely, but is probably more often approximately north than any other direction.

A number of rock types will be described briefly, but there occur many variations, and probably other types could be found. The gneisses and schists, especially near the granite contact, are cut by large dikes and irregular bodies of pegmatite. In some places lens-like masses of pegmatite are inclosed by the gneisses and schists.

GRANITIC GNEISS

In several localities in the pre-Cambrian area, particularly south of the South Arkansas River, granitic gneiss is present. This is composed essentially of quartz and feldspar, with a variable amount of biotite. In some specimens very little quartz is present, when the rock approaches a syenitic gneiss composed essentially of orthoclase, plagioclase, and biotite, with or without hornblende.

HORNBLENDE GNEISS

Hand specimens of this rock are nearly black, but contain lenticular aggregates of white feldspar grains which make the rock appear gneissoid rather than schistose. The microscope shows, in addition to hornblende, considerable orthoclase, a little plagioclase, quartz, magnetite, pyrite, and accessory zircon.

HORNBLENDE SCHIST

This rock bears a close resemblance to the hornblende gneiss, but is very finely laminated and, in some occurrences, carries practically no feldspar. A few grains of quartz, besides minute crystals of zircon and apatite, are present.

Other occurrences of hornblende schist show considerable orthoclase, a little microcline and plagioclase, accessory titanite, but no quartz.

MICA SCHIST

One variety of mica schist is made up of biotite and feldspar in nearly equal quantity, with a very little quartz and accessory zircon. The feldspar is largely in equidimensional grains, with an average diameter of about half a millimeter. Cross-sections of many grains are almost circular. Albite twinning is frequently present, though there are but few lamellæ as a rule. Much of the feldspar is unstriated and may be, in part, orthoclase. Several crystals of feldspar, so cut as to give the emergence of the acute bisectrix, are positive. This, taken with the low extinction angles of sections normal to the albite lamellæ, indicates that the feldspar is largely albite. Biotite has crystallized later than the feldspar and fills the interspaces. In some cases a crystal of biotite extends over a wide area, involving many feldspar grains in an ophitic or poikilitic manner.

Another variety of mica schist contains no feldspar, but is composed of biotite, muscovite, quartz, and a little magnetite. The two micas are commonly intergrown.

GARNETIFEROUS SCHIST

Much of the rock on the dump of the Bon Ton mine is a schist, showing in the hand specimen quartz, biotite, a variable amount of almandite garnet, and a little chalcopyrite. The garnets are 2 to 3 mm. in diameter and are practically without crystal forms. In addition to the minerals mentioned, the microscope shows small zircons inclosed by the quartz, besides many anhedrons of gahnite.

BIOTITE-SILLIMANITE SCHIST

On the steep slope south of Maysville is a variety of schist composed principally of quartz, biotite, sillimanite, and a white, inelastic, laminated mineral which is probably talc. A small amount of magnetite is present, and the microscope shows accessory zircon. The rock is very schistose and cleaves readily.

The sillimanite is found in very small, needle-like crystals which, for the most part, form aggregates. These aggregates occur in mat-like streaks of interwoven tufts and bundles which fray out into the other essential constituents. In addition to this common occurrence, scattering sillimanite crystals are inclosed by the other minerals.

Another variety seen on the ridges on both sides of Greens Gulch, near the south border of the mapped area, is quite different in character. This rock contains numerous white, lens-like masses in a matrix of quartz-mica schist. Ball[1] has described a rock of similar character, though somewhat different in composition, from the Idaho Springs formation of the Georgetown quadrangle, Colorado. Sharp cross-fractures in the lenses mentioned are common, as in the ellipsoidal masses in the Idaho Springs rock.

The lenses commonly have a diameter of less than two inches, but some of them are three inches across. The microscope shows them to be made up principally of quartz and sillimanite. The quartz incloses occasional zircon crystals, and in one slide there is seen a streak of what is probably finely divided muscovite. The quartz incloses many single needles and bundles of sillimanite, but by far the greater part of the sillimanite occurs in bundles and tufts which fray out into the quartz.

The matrix is composed of almost equal quantities of quartz and biotite, with a few flakes of muscovite and an occasional zircon crystal. No sillimanite was observed in the matrix. The quartz of the matrix generally shows undulatory extinction, a phenomenon almost entirely lacking in the quartz of the lenses. This probably indicates that after recrystallization the rock was subjected to dynamic stress, which was relieved almost wholly by the yielding of the matrix, perhaps because of the presence of much biotite in this part of the rock.

ORIGIN OF THE GNEISSES AND SCHISTS

The granitic gneiss has furnished no satisfactory evidence as to whether it was originally sedimentary or igneous. As nearly as can be determined from microscopic examination, the

[1] Ball, S. H., Prof. Paper U. S. Geol. Survey No. 63, 1908, p. 41.

rocks composed principally of quartz, mica, and sillimanite have approximately the chemical composition of argillaceous sandstones or sandy shales, and have probably been derived from such rocks by complete recrystallization in the process of metamorphism. Ball[1] regards as a conglomerate the rock of the Idaho Springs formation which carries the ellipsoidal bodies. The schist with the lenticular masses in the vicinity of Greens Gulch also has the appearance of a metamorphosed conglomerate. It could scarcely be suspected that quartz and sillimanite would segregate in the process of recrystallization of a rock of uniform composition. To suppose the original rock to have been an igneous breccia would be open to objection. An igneous rock having the chemical composition of a mixture of quartz and biotite in nearly equal volume would be unusual, and the approximately uniform distribution of the inclusions would be very improbable. Hence it is inferred that this rock represents the complete recrystallization of an argillaceous, ferruginous sandstone carrying pebbles of argillaceous sandstone.

It is not improbable that some of the schists have been derived from igneous rocks. In some places rock of the same composition will form a band 100 feet or more wide, while the adjacent rock will have a very different composition. Whether the original rocks were sedimentary or igneous, or both sedimentary and igneous, the adjacent layers apparently differed widely in composition. It should not be inferred from the above that the alternations and successions are as uniform over long distances and as well defined as are found in the pre-Cambrian metamorphic rocks in some parts of the Rocky Mountains, as, for example, in the Encampment District, Wyoming.[2]

By way of summary, it may be said that the observations made do not justify a conclusion as to the exact physical character of the original rocks. The most that can be said is: the schists and part of the gneisses indicate metamorphic derivatives of shales, sandstones, and conglomerates, probably intercalated with igneous rocks in the form of flows or minor intrusions or both.

Cross[3] has studied a series of schists near Salida, which is a few miles east of the area under consideration. He "inclines

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[1] Op. cit., p. 44.

[2] See Spencer, A. C., Mineral resources of the Encampment copper region, Wyoming: Bull. U. S. Geol. Survey No. 213, 1903, pp. 158-162. Copper deposits of the Encampment district, Wyoming: Prof. Paper U. S. Geol. Survey No. 25, 1904.

[3] Cross, Whitman, Peculiar series of schists near Salida, Colo.; Pros. Colo. Sci. Soc., 1893, pp. 1-10.

to the belief that the schists and massive rocks of the Salida section * * * represent a great series of surface lavas erupted in Algonkian time."

AGE

The gneisses and schists belong to the complex which has been variously referred to the Archean or Algonkian, or simply pre-Cambrian, by geologists working in Colorado. These gneisses and schists are, at least in large part, the oldest exposed rocks in the area mapped. They are cut by intrusive granite much older than the oldest Paleozoic sediments of the district, which are probably of Upper Cambrian age. After giving a summary of observations made in the Sawatch Range by themselves and other geologists, Van Hise and Leith[1] make the following statement:

> The presence of limestone and quartzite in the pre-Cambrian schists of the Sawatch and adjacent valleys, making up, in the case of the quartzites, the major part of the series, suggests the Algonkian age of this part of the series, but the granites and the other gneisses and schists may be of the same or different ages. Sufficient work has not yet been done to separate them lithologically or structurally. The best that can be done is to refer the entire complex to the pre-Cambrian.

QUARTZITE

Three small areas of quartzite near the southeast corner of the field are shown on the map. About half a mile west of the northernmost area is considerable quartzite talus on the timbered slope.

The quartzite is bluish or reddish and very dense. There remains a suggestion of bedding, but the relation of this to the foliation of the gneiss is not clear. The microscope shows that there has been a complete recrystallization. The interlocking quartz grains resemble the quartz of granite; their form bears no resemblance to the rounded outline of quartz grains in sandstone. The quartz shows a moderate degree of undulatory extinction. Small grains and crystals of magnetite are common; a little hematite is present. The magnetite forms anhedrons and octahedrons. A striking microscopic feature is the large number of crystals with a length three to six times the thickness. These appear to be distorted magnetite octahedrons. Much of the iron ore forms small inclusions in the quartz. The larger grains inter-

[1] Van Hise, C. R., and Leith, C. K., Pre-Cambrian Geology of North America: Bull. U. S. Geol. Survey No. 360, 1909, p. 829.

lock with the quartz grains. A rude banding is noticeable in the slide, owing to a partial segregation of the ore. As a rule, the long dimension of the crystals is parallel to the banding.

ORIGIN OF THE QUARTZITE

This rock was evidently derived from a sandstone whose constituents underwent thorough recrystallization in the process of metamorphism. The considerable quantity of iron ore points to the probability that the cement of the original sandstone was largely ferruginous.

AGE

The structural relation of the quartzite to the gneisses and schists is not evident. The quartzite, however, appears to have undergone as extreme metamorphism as have the schists and is probably of the same general age.

GRANITES

In the area mapped as pre-Cambrian granite are two distinct kinds which differ in habit rather than in composition. These were very likely intruded at different, but not widely separated, times. There are local unimportant deviations from the types. The mapped granites form part of a batholith intruded into the gneisses and schists. For considerable distances the contact is distinct and regular. In many places, however, there are so many inclusions of the metamorphic rocks in the granite and so many minor intrusions of the granite in the metamorphic rocks that the boundary shown on the map separates the two only in a general way.

COARSE BIOTITE GRANITE

Nearly all the country rock in the granite area on the Continental Divide south of Bald Mountain and east of the divide as far north as North Fork, is of the type which will be described as coarse biotite granite, and which doubtless was intruded at one time.

This granite varies in color from gray to red. In the south and southwest part of the exposure the rock is commonly red or pink. The color here is due partly to the reddish feldspar, but is also partly a result of the weathering of biotite. The common megascopic constituents of the granite are feldspar, quartz, and biotite. On the top of the range, about a mile north of Monarch

Pass, the granite, taken from a prospect hole, shows numerous crystals of magnetite.

Much of the granite is even-grained, but a porphyritic facies is present over considerable areas, particularly east of Taylor Gulch, where feldspar phenocrysts one-half to one and one-half inches long, form a large portion of the rock. Very commonly these phenocrysts show a parallelism in orientation, which is probably a fluxional arrangement. In general, the even-grained granite is massive or only slightly gneissoid, but locally granite gneiss has been developed through dynamic metamorphism.

Thin sections carry zircon, iron ore, biotite, plagioclase, orthoclase, microcline, and quartz as primary minerals. Zircon is very rare and in minute crystals. Iron ore occurs in octahedrons inclosed by feldspar and in formless grains in part secondary.

The *biotite* is the usual brown pleochroic variety, and is very commonly chloritized or epidotized. In several specimens, particularly those taken from the Lilly mine, the biotite is in aggregates of minute flakes which appear to have resulted from recrystallization.

Acid *plagioclase* is present in only a few specimens and in small quantity. *Orthoclase* and *microcline* are abundant but bear no constant ratio to each other in amount. On the whole, microcline probably is predominant. Carlsbad twinning is occasionally seen in the orthoclase. In most of the specimens examined there has been considerable kaolinization of all the feldspars.

Quartz is not uncommonly intergrown with the potash feldspars, but these intergrowths are not of the typical graphic variety. Instead, but two or three circular areas of quartz surrounded by feldspar, have the same crystallographic orientation. Undulatory extinction is general in the quartz. This mineral commonly carries numerous liquid inclusions, and in some instances, minute, needle-like microlites which do not react on polarized light. These microlites are possibly rutile.

The two small exposures west of Maysville, mapped as granite, are more monzonitic than the rock described, and a small area on the ridge east of Banana Mountain is similar to the Maysville rock. This differs from the granite described in that it contains less quartz, plagioclase in excess of potash feldspar, and considerable titanite. While it may be a facies of the granite there is no proof that this rock was not intruded independently. The great amount of pegmatite associated with the older metamorphic rocks in the vicinity of Maysville suggests that the exposed monzonitic rock is part of a batholith or very large stock.

PORPHYRITIC GRANITE

Much of the granite of the Tomichi district, including practically all west of Whitepine and east as far as Bald Mountain, has a very different texture from the coarse biotite granite described. The most striking feature of this rock is the great number of tabular feldspar phenocrysts with dimensions commonly less than 4 mm. by 10 mm. The majority of the phenocrysts are twinned after the Carlsbad law. The groundmass, which forms somewhat less than half the volume of the rock, is a granular aggregate of quartz, feldspar, and biotite.

In thin section, most of the phenocrysts are seen to be orthoclase, but a few plagioclase phenocrysts are present. Since all the observed sections of plagioclase normal to (010) have approximately parallel extinction, this feldspar is probably oligoclase. Inclusions of biotite and quartz are common in the feldspar phenocrysts. The freshest specimens show considerable kaolin and sericite derived from the feldspars.

Although considerable biotite, orthoclase, and plagioclase are present in the groundmass, quartz is here the most important component. The quartz very generally shows undulatory extinction in small degree. Microlites, like those in the quartz of the coarse-grained granite, and liquid inclusions are common.

Relation to coarse biotite granite.—No effort was made to map the boundary between these two kinds of granite. The difference between the two is not very evident on weathered surfaces and, furthermore, there is much interlocking and irregularity. Hence the rocks could be separately mapped only at the expense of a great deal of time.

Loose boulders were seen which carry a sharp contact between the two varieties and one boulder showed porphyritic granite inclosing the coarse variety. It is hence inferred that the two kinds of granite were intruded separately and that the coarse variety is probably the older. As nearly as can be determined from microscopic study, the chemical composition of the two varieties is essentially the same. The difference in texture is probably the result of a difference in physical conditions during the process of crystallization.

SMOKY-QUARTZ GRANITE

A rock, which deserves mention because of its peculiar appearance, occurs on Missouri Hill and east of the Rainbow mine. The exposures are small and this rock may be a phase of the surrounding granite or it may be a separate intrusive. The rock is composed essentially of small grains of feldspar and smoky quartz, with a very little magnetite and finely flaked biotite. The microscope shows, in addition, small crystals of apatite and needle-like microlites which do not react on polarized light. The feldspar is orthoclase, microcline, and microperthite.

PEGMATITE AND APLITE

Only a very few narrow dikes of pegmatite and aplite cut the granite itself within the area mapped. Surrounding the granite, however, in a zone of variable width in the area of gneiss and schist, pegmatite is common. A good example is seen south, west, and southwest of Maysville, where pegmatite with large masses of quartz, is abundant.

A large area, crossed by Lost Creek, contains so little gneiss and schist that it has been mapped separately. The rock of this area varies from a coarse pegmatite, having quartz masses a foot or more in diameter, to a coarse acid granite with but little biotite. A few small inclusions of gneiss and schist are present.

AGE OF THE GRANITES

The oldest Paleozoic formation in the Monarch and Tomichi districts is a quartzite which is probably the equivalent of the Upper Cambrian Sawatch quartzite. This formation was laid down on a nearly level granite surface, showing that the granites had been long exposed to erosion. These granites are therefore much older than the quartzite and, as before stated, are younger than the gneisses and schists. They are very probably of pre-Cambrian age, and will be so considered in this report, with the qualification that it is not impossible that they may be of early Cambrian age, as Cross[1] has pointed out.

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[1] Bull. 360, U. S. Geol. Survey, pp. 824, 826.

GRANITE PORPHYRY

About a mile south of Lost Mountain there is an exposure of acid rock which is largely granite porphyry, but near the center is practically granular and might be called aplitic granite. The individual grains have a maximum size of about four millimeters. Feldspar and quartz are readily recognized in the hand specimen. The weathered rock is commonly white, but in places shows a reddish tinge.

Under the microscope are seen plagioclase, microperthite, orthoclase, microcline, quartz, and a little biotite, with secondary iron ore, chlorite, epidote, sericite, and kaolin. Many plagioclase crystals show well-developed forms, while the other feldspars and quartz have crystallized in two periods.

Plagioclase is abundant and is probably albite, possibly in part oligoclase. Although combinations of Carlsbad and albite twins are present, the mineral is too badly sericitized for certain identification. Extinction angles up to 15° were observed in sections normal to the twinned lamellæ, while the difference in extinction between the two Carlsbad halves is very small. A small amount of plagioclase is intergrown with both varieties of potash feldspar. The orthoclase and microcline phenocrysts have very imperfect or almost no crystal outline. In many cases they show, near the border, micrographic intergrowths with quartz. Kaolin and sericite are common alteration products. The quartz phenocrysts are approximately equidimensional but have no crystal outline. A few quartzes show undulatory extinction. Biotite was originally present in very small quantity. It is now almost completely replaced by epidote and chlorite, with the separation of iron ore.

The groundmass, greatly subordinate to the phenocrysts in volume, is a microgranular aggregate of quartz and orthoclase. Quartz greatly predominates, and in some areas, where the amount of the groundmass is very small, quartz is the only mineral.

The mineral composition of this rock is very similar to that of the post-Carboniferous granite.

AGE AND FORM OF INTRUSION

The rock described is so much more weathered than the late acid igneous rocks, and has so nearly the aspect of the ancient granites, that it was regarded in the field as a pre-Cambrian intrusive. However, the microscope brings out the porphyritic texture and only slight evidence of dynamic metamorphism. The pre-Cambrian rocks have been subjected to a great amount of erosion, and hence any pre-Cambrian intrusive that is now exposed, must have solidified at a considerable depth where the temperature would be favorable to slow crystallization. The very siliceous character of this rock, which would tend to offset, in a measure, favorable conditions for slow cooling and consequent granular texture, must not be overlooked. Nevertheless, the existence of considerable fine-grained groundmass, especially around the borders, when taken with the indications of but slight dynamic metamorphism, suggests the possibility that the granite porphyry was, in comparatively late geologic time, intruded as a stock which solidified at moderate depth. For want of better evidence of age, its description is placed in the pre-Cambrian section of this paper.

SYENITE, HORNBLENDITE, AND DIORITE

In the granite area east of Garfield are several intermediate to basic dikes trending in a general northerly direction. Most of these dikes are intrusive into the granite, since they extend long distances, and in most cases are sharply differentiated from the granite walls, apparently forming an eruptive contact. They have, however, shared the regional metamorphism with the granite, and are hence probably but little younger. The most prominent dikes of this class will be described here briefly.

The dike seen at the railway, about 800 feet east of the base of the limestone, is a heavy, dark, fine-grained rock composed of hornblende and subordinate feldspar with considerable titanite and a small quantity of magnetite. The microscope shows the feldspar to be microcline and plagioclase in about equal quantities. Many hornblende crystals have well-developed crystal faces.

The Bay State and Independence tunnels, about a mile north of the railroad, cut a similar, or probably the same, dike. The rock in the specimens examined differs from that at the railroad chiefly in that the feldspar is all orthoclase. This dike, or one parallel to it, can be traced northward nearly half a mile to a point where it passes under the moraines.

A few feet east of the first dike mentioned is one of hornblendite composed chiefly of hornblende but carrying some pyrite. A narrow dike of hornblendite crosses the ridge southeast of the Clinton mine. This rock is very fine in texture, and carries, in addition to the hornblende, a small amount of orthoclase and plagioclase.

A strong dike of diorite about a mile and a half east of Garfield, is approximately parallel to those farther west. It is slightly porphyritic, having a few plagioclase phenocrysts in a fine-granular groundmass of hornblende and plagioclase. The rock shows evidence of having been folded and squeezed. Although the dike appears to be intrusive it does not show walls as well defined as do some of the others, and is itself cut by pegmatite veins a fraction of an inch to several inches wide.

On the first hill north of the point where the last-mentioned dike is exposed at the railroad, a diorite dike with an eastward trend may be seen. This diorite is even-grained and composed of feldspar and dark minerals in approximately equal amounts. Hornblende is the predominant dark mineral, but the microscope shows considerable augite and magnetite. Extinction angles indicate that the feldspar is basic andesine or acid labradorite.

Relation to the granite.—It will be noticed that the dikes described have essentially the composition of lamprophyres, but differ from the latter in texture. The texture is about what might be expected in a rock of lamprophyric composition solidifying under conditions which favor slow crystallization, that is, at high temperature. May not these dikes be the deep-seated extension of lamprophyric dikes whose upper part has been removed by erosion? If so, they may be considered the femic differentiate of the granitic magma and complementary to the pegmatite mentioned on a preceding page.

CHAPTER IV

PALEOZOIC SEDIMENTARY ROCKS

Although Paleozoic sediments are exposed over only a small part of the area mapped, there are reasons to believe that the entire area was once covered by nearly or quite all of the formations now represented. Among these reasons are: (1) the close lithological resemblance between separated areas of each formation; (2) the virtual absence of shore deposits from the limestone formations, thus indicating a considerable distance of land masses from the area at the time of deposition of the sediments; (3) the presence on both sides of the Continental Divide of all the formations of the region, excepting the youngest one, whose absence from the Tomichi district can easily be explained by its removal through faulting and erosion; and (4) the presence of Paleozoic sediments north of Monarch Pass on the crest of the Sawatch Range. The crest of the range, where it was involved in anticlinal folding, would be more likely than any other part to be above sea-level while the remainder of the area was receiving sediments; but if this part had been exposed longer than the rest it is highly probable that, with its consequent less total thickness of sediments and its position and structure favorable for rapid erosion, all of the sediments would have been removed long ago. The age of this part of the range is further discussed in the chapter on structural geology.

Excepting a few beds, most of the sedimentary rocks in the region are poor in well-preserved fossils. This poverty is doubtless owing, in large measure, to the dolomitization of the limestone and the contact metamorphism to which most of the sediments have been subjected. It is probable that a paleontologist if given sufficient time, could find more species than are recorded here, and a stratigrapher would doubtless make further stratigraphic subdivisions. Partly on paleontologic, partly on lithologic grounds, the sediments of this region can easily be divided into at least five formations. Since three of these cannot be definitely correlated with previously described formations it has seemed advisable to use new formation names. The three formation names proposed in this paper have been considered and approved by the United States Geological Survey's Committee on Geologic Names. Generalized vertical sections of the Paleozoic sediments of the two districts are given at the end of this chapter.

CAMBRIAN SEDIMENTS

SAWATCH QUARTZITE

Near the northwest corner of the Tomichi district the granite is overlain by about twenty feet of quartzite which can be followed almost a mile along the strike of the bed. The rock is white and very hard and composed mainly of sand grains, one or two millimeters in diameter, in a siliceous cement. The quartzite is quite uniform in color and texture from the lowest exposure to the top. A small part of the formation at the base is covered by talus and soil. On the west slope of Lake Hill the same quartzite has been uncovered in two shallow prospect pits, and it is also seen in an inclined shaft on West Point. In these places the bed is probably less than five feet thick. A small remnant of quartzite is also exposed about three-quarters of a mile south of West Point, on a hill from which all the limestone has been removed by erosion.

In the Monarch district this quartzite is not anywhere exposed at the surface. However, in the Clinton and Lilly mines north of Garfield and in the Evening Star tunnel on Monarch Hill, remnants of quartzite from a few inches to a few feet thick may be seen between the granite and limestone.

Conditions of deposition.—The small amount of Sawatch quartzite remaining in this district is made up almost entirely of well-washed quartz sand. It was, therefore, probably deposited in shallow waters near the seashore. The granite floor on which this sand was laid down seems to have been reduced to a comparatively flat surface before the sand was deposited. Certainly it was so reduced before the deposition of the succeeding limestone after an erosion interval insufficient for the complete removal of the Sawatch quartzite.

Age.—No fossils have been found in this formation in the area under consideration. Because of its stratigraphic position and lithologic character, it is thought to be a remnant of the lower division of the Sawatch quartzite[1] which has been described from several districts of central Colorado. Upper Cambrian fossils[2] have been reported from the upper division of the Sawatch quartzite in most of these districts.

ORDOVICIAN SEDIMENTS

TOMICHI LIMESTONE

The sediments referred to the Ordovician system comprise about 400 feet of limestone and quartzite, the former predominant. The basal part is limestone which lies unconformably on the Sawatch quartzite where the latter is present, and which rests directly on the pre-Cambrian granite where that quartzite is absent. These beds are well exposed in the Tomichi district, and for this reason the name Tomichi limestone is here proposed for the formation. With but slight variation in character, the limestone is continuous in most of the outcrops for 230 to 290 feet. Near the top of this limestone, in at least part of the field, is a more or less sandy bed about fifteen feet thick. A few feet above the sandy limestone is a persistent bed of quartzite, locally called "parting quartzite."

The "parting quartzite" varies from twenty to thirty-eight feet in thickness. It is succeeded by about 100 feet of limestone which grades into dolomitic limestone, followed by a few feet of argillaceous limestone and calcareous shale. For purposes of mapping, the shale stratum has been taken as the upper limit of the Ordovician sediments. The following is a section of the Ordovician beds east of Garfield exposed along the creek:

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[1] See the following:

Emmons, S. F., Geology and mining industry of Leadville, Colorado: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 58. (The formation is called Lower quartzite in Emmons' report.)

Eldridge, G. H., Anthracite-Crested Butte Folio (No. 9), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

Emmons, S. F. Tenmile Folio (No. 48), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

Girty, G. H., Carboniferous formations and faunas of Colorado: Prof. Paper U. S. Geol. Survey No. 16, p. 140.

[2] Loc. cit.

Section of Ordovician sediments east of Garfield

		Feet
11.	Thick-bedded, non-cherty, gray limestone, dolomitic in upper part .... about	100
10.	Thick-bedded, bluish quartzite, with limonite stain on surfaces	18.5
9.	Banded quartzite, mostly white with bluish-gray streaks; frequent specks of brown ferric oxide in the white quartzite. Most of the quartzite is coarse-grained	14
8.	Bluish quartzite, coarse-grained, with siliceous cement	5
7.	Mostly thin-bedded limestone, partly cherty; contains a few feet of sandy limestone near the top	46
6.	Thin-bedded, light-gray limestone. Small fibers of asbestos-like mineral, probably tremolite, in upper part	9
5.	Thick-bedded, bluish-gray, cherty limestone	112
4.	One stratum of blue limestone, with a few small veins of calcite	2
3.	Thick-bedded, bluish-gray limestone, with chert nodules. Nodules are continuous in places and form seams up to three inches thick	60
2.	Thick-bedded, bluish-gray limestone	7
1.	Thin-bedded, bluish-gray limestone, resting on granite	9
		382

Limestone.—In the Garfield mine, east of Taylor Gulch, the limestone below the "parting quartzite" has a thickness of 290 feet; east of Garfield the thickness is about 260 feet; in the Eclipse mine, on Monarch Hill, the thickness is 235 feet. There is a gradual thinning as the limestone is followed toward the southwest extremity of the synclinal fold. On the west limb of the fold, from the Madonna No. 6 tunnel northward, the limestone is partly cut out by a fault. The Madonna No. 6 tunnel, which was started apparently very near the granite-limestone contact, cut the "parting quartzite" at ninety feet from the tunnel entrance. Making allowance for the dip of the beds and the possibility of error in locating the contact between the granite and limestone, it is probable that the lower limestone is between eighty and ninety feet thick in this tunnel. North of the creek, a crosscut from the Monarch Contact tunnel and a drift following the west border of the "parting quartzite" for some distance show that the thickness of the limestone between the granite and quartzite is about seventy-five feet in this locality. In the Tomichi district the limestone below the quartzite has a thickness about equal to that of the same limestone east of Garfield.

The reduced thickness south and southwest of Monarch points to one of two possibilities: (1) that the deposition of the limestone in this vicinity was less than elsewhere, or (2) that more of the originally deposited limestone had been removed by erosion prior to the deposition of the "parting quartzite." Because of the nearly uniform character of the limestone and the lack of paleontological evidence it is impossible to say which of these is the true explanation. In view of the abrupt change from limestone of varying thickness to a coarse siliceous quartzite it would seem probable that the quartzite lies unconformably on the limestone.

In the Monarch district nearly all the Ordovician limestone is bluish-gray, very fine-textured, and thick-bedded. Excepting a few feet at the base, the limestone is strongly magnesian. Two analyses are given below:

Analyses of Ordovician limestone

[R. M. Butters, Analyst]

	1	2
SiO_2	3.24	3.68
Al_2O_3	2.72	3.20
Fe_2O_3	1.80	0.64
MgO	1.88	14.07
CaO	48.80	34.33
H_2O	1.14	1.27
CO_2	40.50	42.54
	100.08	99.73

1. Limestone 5 feet above base.
2. Limestone 210 feet above base.

Most of the limestone contains nodules of dark-gray chert. Locally the chert may form a continuous band, having a maximum thickness of about three inches. Above the "parting quartzite" there is comparatively little chert. West of Monarch, at Cree Camp, and on the southwest slope of Missouri Hill, the limestone below the quartzite has been changed by metamorphic processes to a coarse, white marble. Much of the limestone of the Tomichi district in the same stratigraphic position is crystalline, but not so thoroughly metamorphosed as that west of Monarch and on Missouri Hill. On Monarch Hill, a few feet below the "parting quartzite" is a good exposure of the sandy stratum observed in several outcrops. This stratum, which is here nearly fifteen feet thick, is composed mainly of arenaceous limestone alternating with a few thin layers of calcareous sandstone.

Quartzite.—Although this quartzite is often called "parting quartzite" by residents of the region, it is not intended here to attempt to correlate it with the Parting quartzite of the Leadville and Aspen districts. It is present on both sides of the divide, and is the best horizon-marker in the Paleozoic sediments. East of Garfield the quartzite is about thirty-eight feet thick. It gradually thins toward the southwest end of the synclinal fold, and thence northward. It is about twenty feet thick in the Madonna No. 6 tunnel on the west limb of the fold. About a mile northwest of Monarch Pass the quartzite is thirty-four feet thick. In general, the quartzite is fairly uniform in character. It is composed essentially of rather coarse sand grains with a siliceous cement. It is commonly blue to gray on fresh surfaces, but weathered outcrops are generally white to reddish or brown.

Near the northwest corner of the Tomichi district a small detached block of this quartzite was found, which shows on one face parallel to the bedding many impressions of cubes. The impressions are nearly a quarter of an inch across and have very smooth sides. That these are the impressions of fluorspar crystals is shown by the presence of a few remnants of fluorspar cubes. The fluorspar was apparently precipitated from a supersaturated solution of sea water on the sandy bottom. Around the crystals formed, more sand was deposited. After solidification of the sand, possibly within comparatively recent geologic time, most of the fluorspar was removed by solution. A careful search failed to disclose similar impressions in place. Although the phenomenon was perhaps local, the crystals had been closely packed in the specimen examined, thus showing a high concentration of the solution from which they were deposited.

Shale beds or lenses, with a maximum thickness of about two feet, lie between quartzite strata in some of the exposures. These may be more common than they appear to be, since they easily escape observation except where the loose material is rapidly removed by erosion.

Where the beds dip at a moderate angle the quartzite forms prominent outcrops as on Monarch Hill and northwest of Monarch Pass. Where the beds are nearly vertical the quartzite offers but little more resistance than does the limestone and is conspicuous only because of difference in color from that of the underlying and overlying limestone.

Conditions of deposition.—Most of the formation indicates deposition in clear water at considerable depth. Typical shore deposits are not present below the "parting quartzite," although the sea was probably shallower when the sandy stratum near the top of the lower limestone was laid down. The greater part of the "parting quartzite" was probably deposited in shallow water near the shore. The shale lenses in this quartzite suggest a greater removal from shore or storm conditions on the land, or both. There was evidently a return to clear-water conditions while most of the upper limestone was being laid down.

Age.—The lowest beds of the limestone described have yielded no fossils. On Monarch Hill *Helicotoma* sp. and undeterminable cephalopods were found fifty feet above the base. About ten feet higher, poorly preserved specimens of *Dalmanella,* probably *D. testudinaria,* were found. Specifically unidentified *Orthoceras* specimens, much silicified, were collected from the limestone about eighty feet above the base and upward to the "parting quartzite." Doctor Ulrich and Professor Henderson have each identified *Receptaculites oweni* found in the limestone immediately above the quartzite and upward about fifty feet. *Halysites catenulatus* and small cup corals accompany the *Receptaculites*, while the cup corals extend upward about 100 feet above the quartzite.

It is probable that the upper limestone is not younger than the Trenton limestone of New York of late Middle Ordovician, or Mohawkian, time. The fossils from the lower limestone also indicate a Middle Ordovician horizon, though it is probable that there is a stratigraphic break at the base of the "parting quartzite."

Fossil species collected are too few to justify a correlation of the Tomichi limestone with type sections. It should be mentioned, however, that Walcott's[1] list of fossils from the lower

[1] Walcott, C. D., Preliminary notes on the discovery of a vertebrate fauna in Silurian (Ordovician) strata: Bull. Geol. Soc. America, vol. 3, 1892, pp. 153-171.

part of the Fremont limestone, near Canon City, Colorado, includes *Receptaculites oweni* and *Halysites catenulatus*, both of which have been found in the Tomichi limestone above the "parting quartzite." Neither of these species is noted from the Harding sandstone below and *Receptaculites oweni* is not included in the list of fossils from the upper part of the Fremont limestone. The lithological character of the formation described suggests a possible correlation of the lower limestone member, the "parting quartzite," and the upper limestone with the Manitou limestone, Harding sandstone, and Fremont limestone, respectively.[1]

DEVONIAN-MISSISSIPPIAN SEDIMENTS

OURAY LIMESTONE

The shaly bed about 100 feet above the "parting quartzite" is taken as the base of the Ouray limestone as it is shown on the accompanying geologic maps. The upper boundary is placed at the base of quartzite and conglomerate beds 570 to 800 feet higher. The thickness of the Ouray formation, as here taken, is about 570 to 700 feet on Monarch Hill, 800 feet in Taylor Gulch, and 800 feet in the Tomichi district. This is much thicker than the described Ouray in other parts of Colorado.[2] The vertical range of the Ouray fauna on Monarch Hill is about 300 feet.

The beds between the highest determined Ordovician horizon and lowest determined Devonian horizon are less than 150 feet thick. They change rapidly in character vertically, being in part nearly pure lime carbonate and in part variably dolomitic, shaly, and arenaceous. Although one or more stratigraphic breaks may be present, the beds show no angular unconformity.

There is no single exposure of the Ouray limestone in the Monarch district suitable for the detailed measurement of an entire section. The lower half of the section given below was measured in the Eclipse No. 4 tunnel on Monarch Hill. The upper half was calculated from data obtained from surface observations.

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[1]See Pike's Peak Folio, U. S. Geol. Survey, Folio 7, 1894.

[2]For name and stratigraphic relations see Kindle, E. M., The Devonian fauna of the Ouray limestone: Bull. U. S. Geol. Survey No. 391, 1909.

Section of Ouray limestone on Monarch Hill

		Feet
12.	Gray to blue dolomitic limestone.........................	about 140
11.	Black dolomite	about 40
10.	White to gray limestone, much of which weathers to yellow..	about 250
9.	Blue magnesian limestone..	21
8.	Blue limestone, mostly very fine-grained; coarsely crystalline in lower part, and containing imperfect casts of brachiopods........	42
7.	Bluish-gray siliceous limestone..................................	18
6.	White dolomitic limestone...	18
5.	Hard, mottled argillaceous limestone............................	17
4.	White dolomitic limestone...	5
3.	Dark-gray argillaceous limestone................................	12
2.	Hard, brown calcareous shale and mottled argillaceous limestone..	7
1.	Crumbly shale......................................2 inches	
		570

The basal part of the formation, for about eighty feet, is more or less argillaceous or arenaceous. Much of it weathers to red or chocolate-brown, making it a good horizon-marker in unmetamorphosed areas. Most of the limestone is heavy-bedded and, where not metamorphosed, is very dense. Excepting that south of the railway in the Monarch district and in a comparatively small area near the southeast corner of the Tomichi district the Ouray limestone is more or less coarsely crystallized. The limestone is mainly gray to blue on fresh surfaces. Weathered surfaces are generally gray, but on Monarch Hill much of the limestone weathers to yellow or nearly white. About 150 feet below the top of the formation is a bed of black dolomite twenty to forty feet thick, No. 11 of the section. South of Monarch, where it is not coarsely crystallized, the black dolomite carries many fossils. Near the head of Taylor Gulch this rock is thoroughly metamorphosed and cannot be distinguished from the other beds. In the Tomichi district it is dark gray to black and coarsely crystalline. No fossils were found in the Ouray formation above the black dolomite, but since the overlying limestone is strongly dolomitic and appears to be conformable on the black dolomite it is included on the map with the determined Ouray beds.

Although nearly all of the Ouray limestone is magnesian or dolomitic, about half-way up in the formation is a bed composed of almost pure calcium carbonate. At Garfield, where it is extensively quarried for flux, this bed is nearly 100 feet thick, is mostly blue in color and thoroughly crystallized. The table below gives analyses of two samples of limestone and one of dolomite from the Ouray formation. For comparison, the theoretical composition of normal dolomite, $CaCO_3.MgCO_3$, is also given.

Analyses of limestones and dolomite by R. M. Butters, and theoretical composition of normal dolomite

	1	2	3	4
SiO_2	18.16	0.12	0.34	...
Al_2O_3	15.34	0.20	0.16	...
Fe_2O_3	3.81			...
MgO	3.94	13.55	20.07	21.9
CaO	25.88	38.56	32.12	30.4
H_2O	8.28	2.30	0.00	...
CO_2	24.62	45.32	47.37	47.7
	100.03	100.05	100.06	100.0

1. Argillaceous limestone from No. 3 of the section.
2. Magnesian limestone, 240 feet above base of Ouray formation.
3. Black dolomite, No. 11 of section.
4. Theoretical composition of normal dolomite.

The following table gives analyses of Ouray limestone by the chemist of the sugar factory at Rocky Ford:

Analyses of Ouray limestone

	1	2	3	4	5	6
Insoluble	0.54	0.18	0.24	1.45	3.60	6.67
Al_2O_3, Fe_2O_3	0.25	0.22	0.70	0.83	0.63	1.00
$MgCO_3$	1.48	0.80	2.95	41.93	40.60	34.73
$CaCO_3$	98.31	98.54	96.67	56.49	55.80	55.17
Undet.	...	0.26	...	...	...	2.43
	100.58	100.00	100.56	100.70	100.63	100.00

1. Crystallized limestone near center of face of Garfield quarry.
2. Average of twelve samples across quarry face.
3. Limestone about 350 feet west of quarry.
4. Dolomite 40 feet west of No. 3.
5. Dolomite 40 feet west of No. 4.
6. Dolomitic limestone 40 feet west of No. 5.

It is probable that the stratum from which No. 4 was taken is the same as 11 of the section.

In several places the dolomitic limestone near the top of the formation is succeeded by one or several beds of shale which is here included with the Ouray. The thickest shale bed observed is exposed east of Garfield on the north side of the creek. Here the limestone is overlain by a two-foot stratum of quartzite which is in turn followed by fourteen feet of shale. Massive garnet and graphitic marble have been developed in considerable quantity in this zone west of the head of Taylor Gulch. Shale is also seen above the dolomitic limestone east of Monarch at the portal of the Great Monarch tunnel, and in many prospect holes in the Tomichi district. Just south of Monarch this shale is absent, owing probably to removal by erosion prior to the deposition of the succeeding supposed Pennsylvanian beds.

Conditions of deposition.—Nearly all the Ouray formation was laid down in a clear, quiet sea, and hence probably at considerable distance from the shore. The virtual absence of mechanical sediments indicates that the streams were bringing from the probably base-leveled land area considerable material in solution and very little in suspension. There is no satisfactory evidence at hand by which the time of dolomitization can be determined. Toward the close of Ouray time, a relative elevation of the land or storm conditions, or both, enabled the streams to carry chiefly suspended material which now constitutes the shale near the top of the formation.

Age.—Girty,[1] has recorded the following Devonian fossils collected by Eldridge from the Ouray limestone of Monarch Hill:

Monotrypella sp.
Schizophoria striatula=S. striatula var. australis Kindle[2]
Orthothetes chemungensis=Schuchertella chemungensis (Conrad) Kindle[3]
Orthothetes chemungensis var.
Productella semiglobosa=P. coloradoensis Kindle[4]
Productella subalata?
Productella subalata var.
Athyris coloradoensis
Spirifer disjunctus var. animasensis=S. whitneyi var. animasensis (Girty) Kindle[5]
Camarotoechia endlichi (Meek) Schuchert
Camarotoechia contracta?
Straparollus clymenioides?
Orthoceras sp.

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[1] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 36.

[2] Kindle, E. M., The Devonian fauna of the Ouray limestone: Bull. U. S. Geol. Survey No. 391, 1909, p. 21.

[3] Idem, p. 16.

[4] Idem, p. 17.

[5] Idem, p. 25.

Near the portal of the Eclipse No. 3 tunnel on Monarch Hill many fossils are found in the limestone, which is here very dense and emits a bituminous odor when broken. Since the limestone shows no bedding the exact dip and stratigraphic position are indeterminable. It is probable, however, that the lowest fossils are found eighty to 100 feet above the pink, shaly bed which is here taken as the base of the Ouray limestone. The following genera and species were collected from this limestone:

Monotrypella sp.
Schizophoria striatula var. australis Kindle
Schuchertella chemungensis (Conrad) Kindle
Athyris coloradoensis Girty
Spirifer whitneyi var. animasensis (Girty) Kindle
Camarotoechia endlichi (Meek) Schuchert
Camarotoechia contracta (Hall)?

On account of the structureless character of the limestone on the dip slope where these fossils were found, it is difficult to determine the thickness of the fossiliferous zone. It is not likely, however, that the fossils range through more than fifty feet. A few poorly preserved specimens of a gastropod were collected from the limestone about fifty feet below the black dolomite and approximately 200 feet above the beds which contain the fossils noted above. These have been generically identified with some uncertainty by Professor Henderson as *Straparollus*.

The Mississippian fossils collected by Eldridge from the black dolomite south of Monarch and described by Girty,[1] are:

Syringopora aculeata Girty
Syringopora surcularia Girty
Spirifer centronatus Winchell

The bed in which these fossils were found, Girty correlates with the Carboniferous portion of the Leadville limestone, which he refers to early Mississippian age.[2]

In the course of the present survey the following were collected from the same bed:

Zaphrentis sp.
Streptelasma? sp.
Syringopora aculeata Girty
Syringopora surcularia Girty
Spiriferina solidirostris White

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[1] Girty, G. H., Carboniferous formations and faunas of Colorado: Prof. Paper, U. S. Geol. Survey No. 16, 1903, pp. 273, 285, 531.

[2] Op. cit., p. 170.

Near the David H. mine in the Tomichi district where the black dolomite is thoroughly crystallized, *Surcularia* and cup corals are abundant.

Girty,[1] in 1900, summarized the early literature on the Devonian of Colorado and described the fauna of the Ouray limestone, which he considered representative of late middle or early upper Devonian time. More recently Kindle[2] brought the summary of the literature up to date and further described the Devonian fauna which, he states, represents an Upper Devonian horizon. Kindle also gives lists of Mississippian fossils from the upper part of the Ouray limestone and discusses the stratigraphic relations of the two faunas. He shows that the two faunas are distinct and points out lithologic differences between the upper and lower parts of the Ouray limestone.

In the Monarch area no Devonian species have been found in the black dolomite, nor were any Mississippian species found below this bed. Careful search was made for fossils in the limestone immediately below the black dolomite, in order to determine whether or not the sharp lithologic change here might mark the division between the Devonian and Mississippian systems. But no specifically determinable fossils were found between the fossiliferous zone near the base of the Ouray and the black dolomite of Mississippian age. The apparent scarcity of fossils in this part of the formation agrees with Kindle's[3] observation that the two faunas are generally, if not always, separated in the sections by beds which are quite barren.

PENNSYLVANIAN SEDIMENTS

GARFIELD FORMATION

The name Garfield formation is here proposed for the sediments including conglomerate, quartzite, sandstone, shale, and limestone, which overlie the Ouray limestone with apparent unconformity. The thickness of this formation is about 2,600 feet west of Taylor Gulch, and about 2,800 feet on Syncline Hill. In the Tomichi district the thickness is only a few hundred feet; here erosion has probably removed much more than now remains.

[1]Girty, G. H., Devonian fossils from southwestern Colorado: the fauna of the Ouray limestone: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 25-81.

[2]Kindle, E. M., The Devonian fauna of the Ouray limestone: Bull. U. S. Geol. Survey No. 391, 1909.

[3]Op. cit., p. 13.

At the base are quartzite and conglomerate beds about thirty feet thick. East of Garfield, along the creek below the Lilly tram terminal, the following section is exposed:

Section of basal part of Garfield formation east of Garfield

		Feet
4.	Fine-grained, gray quartzite	2
3.	Bluish quartzite conglomerate, containing chert pebbles up to one inch in diameter and smaller quartz pebbles	2
2.	Fine-grained, dark-blue quartzite	17
1.	Very coarse, dark-blue quartzite overlying 14 feet of shale	9

About 300 feet northeast of the Fairplay mine at Monarch the basal member of the Garfield rests on the Ouray limestone with no intervening shale. In the outcrop, which is small, the following section was measured:

Section of basal part of the Garfield formation at Monarch

		Feet
8.	Coarse quartzite conglomerate, carrying chert pebbles	6
7.	Dark-gray siliceous limestone	3
6.	Chert conglomerate (chiefly chert pebbles with small amount of dolomitic matrix)	2
5.	Gray limestone with marcasite concretions; sandy near top	3
4.	Intraformational conglomerate (blocks of gray limestone, 6 inches in diameter, in a matrix of coarse quartzite)	3
3.	Bluish-gray limestone	2
2.	Gray limestone with marcasite concretions	8
1.	Coarse, blue-gray quartzite (lower 2 feet conglomeratic, having chert pebbles up to 1 inch in diameter)	7

Excepting the two small outcrops in which the above sections were measured, there is no good exposure of the basal part of the Garfield formation in the Monarch district. West of Taylor Gulch the relations between the Ouray and Garfield formations have been obscured by contact metamorphism which has resulted, in one place, in a mass of garnet thirty-five feet thick, besides several smaller seams. In the Tomichi district there is no good outcrop of the basal part of the Garfield formation, but the horizon can be readily traced by the aid of dumps at numerous prospect holes which show quartzite, conglomerate, and black shale or graphitic material.

The first 700 feet of sediments which overlie the quartzite and conglomerate mentioned is mainly black shale with comparatively thin strata of quartzite and impure limestone. In the

Monarch district the shale is mostly covered by superficial material, and only isolated outcrops may be seen. In the metamorphosed areas west of Taylor Gulch and in the Tomichi district the shales vary from ordinary indurated shale to hornfels.

Beginning at about 750 feet from the base of the formation and extending upward nearly 200 feet, the sediments are chiefly interstratified limestone and black shale. The shale, which exceeds the limestone in quantity, is more or less calcareous. The limestone varies from bluish-gray, fairly pure limestone to black shaly limestone. The fossils noted below were found in these shales and limestones.

The middle third and upper third of the formation are made up of shale, shaly limestone, and quartzite or sandstone. The middle third is more calcareous than the upper third, while the upper third contains more sandstone and quartzite. Any of the rocks named may be in comparatively thin layers, or in beds twenty feet thick or more.

Much of the shale is calcareous and, where very hard, is difficult to distinguish from the black limestone. Many of the shale beds on Syncline Hill have been altered to cordierite hornfels and closely resemble the quartzite in appearance. They can usually be distinguished from the quartzites by their greater hardness and their metallic clink under the hammer. Weathered surfaces of the metamorphosed shale are commonly stained brown by iron oxide.

The limestone varies from a dense rock showing bedding, to structureless graphitic marble. The dense variety very commonly shows many disseminated grains of marcasite.

Very little true sandstone is present but quartzite is common in the upper part. It varies in texture from fine to coarse, but could scarcely be called conglomeratic. Dark blue is perhaps the prevailing color of the freshly broken rock. Some beds, however, are light gray; others, owing to the presence of graphite, are nearly black. Weathered surfaces are commonly brown. On the east shoulder of Taylor Mountain much of the quartzite has, on weathered surfaces, the appearance of the ancient schists. This is caused by the segregation of the dark minerals, which include much biotite, along bedding planes.

Conditions of deposition.—The Garfield formation was almost entirely laid down in shallow water. Progressive subsidence relative to the adjacent land, with probable temporary halts, characterized the submerged area during the accumulation of nearly 3,000 feet of sediments. The basal member is essentially a shore deposit, consisting mainly of well-washed sand and some gravel now consolidated. The carbonaceous material near the middle of the basal quartzite beds indicates an adjacent base-leveled land area.

The shale strata, about 700 feet thick, which succeed the basal quartzite, record flood conditions on the land or off-shore deposition, or both. The overlying limestone strata, which were deposited in comparatively clear water, form a very small fraction of the entire formation. These are more or less impure from the admixture of clayey and carbonaceous material and alternate with beds of shale. The upper part of the formation records many changes which may include variations in depth of water, in currents, in relief of the land, and in climate. In general, however, there seems to have been a more or less gradual shoaling of the water toward the end of this epoch of sedimentation.

Age.—The lowest bed in which Pennsylvanian fossils were found is about 750 feet above the base of the formation. Professor Henderson has identified the following genera and species collected between this horizon and one about 200 feet higher:

1. Fenestella sp.
2. Rhombopora lepidodendroides Meek
3. Chonetes geinitzeanus Waagen
4. Chonetes sp.
5. Derbya? sp.
6. Productus semireticulatus var. Hermosanus
7. Productus inflatus McChesney
8. Productus cora d'Orbigny
9. Spirifer rockmontanus Marcou
10. Spirifer sp., the form commonly referred to S. boonensis Swallow
11. Aviculopecten sp.
12. Pseudomonotis sp.
13. Pleurophorous subcostatus Meek and Worthen
14. Edmondia cf. gibbosa Geinitz
15. Calamites sp.

Nos. 4, 7, 8, 13, and 14 were collected from the upper part of a hard shale bed about twenty-five feet thick, the lowest outcrop shown in Plate XII; Nos. 11 and 12 were found in the talus near by. No. 7 was also found about forty feet higher in the upper part of a shale bed and lower part of an overlying limestone stratum. Nos. 8 and 9 were collected from a blue limestone about six feet higher. Nos. 1, 2, 3, 5, 6, 7, 8, 9, and 10 were collected from what is apparently the same zone near the fault toward the west where the beds stand vertical. The specimens of *Calamites* were found in a black shale near the fault about 200 feet higher stratigraphically than the lowest fossil-bearing horizon.

These fossil-bearing strata are referred to the Pennsylvanian system, without an attempt to correlate them specifically with any of the described formations of other areas. The underlying beds, about 750 feet thick, which apparently unconformably overlie the Ouray limestone, are included provisionally with the known Pennsylvanian strata with which they are conformable in bedding. It is possible, though not probable, that these lower beds may in part belong to the Mississippian system. According to Girty,[1] all the known Mississippian sediments of Colorado represent only early Mississippian time. Elevation and erosion preceded the deposition of Pennsylvanian sediments. It is highly probable that the quartzite and conglomerate at the base of the Garfield formation are the oldest Pennsylvanian rocks in the region. Since no unconformity has been observed in that part of the Garfield formation which overlies the beds containing fossils it is also provisionally included with the determined Pennsylvanian.

PERMO-PENNSYLVANIAN (?) SEDIMENTS

KANGAROO FORMATION

For all the sedimentary rocks which overlie the Garfield the name Kangaroo formation is here proposed, after Kangaroo Gulch where the lowest beds are well exposed. This formation reaches its maximum development along Middle Fork where it has an apparent thickness of about 3,000 feet. It is possible that some of the strata are repeated as the result of faulting, though no evidence of faulting which could produce such an effect has been observed. Since the formation has been cut off by the quartz monzonite intrusion the original thickness was probably even greater than the present. Talus, glacial deposits, and soil cover the greater part of these beds. Where exposed, most of the strata dip steeply toward the west or stand vertical. Locally they are slightly overturned, dipping east a few degrees from vertical. On Syncline Hill the formation is only about 450 feet thick; the

[1] Prof. Paper U. S. Geol. Survey No. 16, 1903, p. 170.

greater part has been removed by erosion. If any part of the formation was deposited in the Tomichi district, it has been completely removed by faulting and erosion. That these beds formerly extended across the divide into that district is indicated by large masses of sediments, having similar mineral and textural character, inclosed in the volcanic breccia south of Vulcan Mountain.

The conglomerate at the base of the Kangaroo formation overlying the Garfield shales indicates an unconformity. No very good evidence of an angular unconformity was found, but this may be because of the poor exposures at this horizon. The upper part of the Garfield formation is commonly covered with talus.

The Kangaroo formation is composed essentially of quartzites, conglomerates, and metamorphosed shales. Unmetamorphosed sandstone is practically absent. The rocks are generally gray, often with brown, blue, or light-green tones. The commonest rock is coarse-grained quartzite, which is in many beds very feldspathic. The microscope shows abundant finely crystallized biotite filling the interstices in some specimens, indicating a ferruginous cement in the original sandstone or arkose. Other specimens contain no biotite, but considerable epidote and much tremolite have been developed through metamorphism. These minerals point to a somewhat calcareous cement in part of the original sediments. Near the lower part of the formation quartzite conglomerate is found at several different horizons. The pebbles of the conglomerate range in size from a fraction of an inch to at least three inches in diameter. The smaller pebbles are chiefly of quartz; the larger ones are of granite. The shales and their metamorphic equivalents are commonly dark in color. They range from very hard shale, in which the development of metamorphic minerals is not noticeable to hornfels which often carries abundant cordierite in small grains.

There is no exposure of a complete section of this formation. The most prominent outcrop is in a small area on the slope east of Kangaroo Gulch where the beds are vertical and stand out prominently above the surrounding sliderock. Here, and west of the gulch, the following section was measured:

Lower part of Kangaroo formation

		Feet
15.	Quartzite and quartzite conglomerate, chiefly; partly covered	400+
14.	Covered, gulch	250
13.	Quartzite and quartzite conglomerate	50
12.	Hornfels	35

11.	Calcareous sandstone or sandy marble, with limonite concretions and limonite stain	2
10.	Hornfels or indurated shale	15
9.	Medium-grained white quartzite	8
8.	Indurated shale	2
7.	Quartzite	30
6.	Medium to coarse quartzite; contains beds with pebbles one-fourth inch in diameter	12
5.	Cordierite hornfels, containing marcasite or pyrite	6
4.	Quartzite conglomerate, having pebbles up to one inch in diameter.	0.5
3.	Coarse quartzite	45
2.	Hornfels, part of which carries abundant cordierite	40
1.	Coarse quartzite	6+

On the divide north of Clover Mountain the volcanic breccia incloses large masses of arkose and sandstone ranging from light greenish-gray to deep red in color. These rocks are but very slightly metamorphosed and have a cement which is in part calcareous. They may be considered the unmetamorphosed equivalent of many of the quartzites farther east.

Conditions of deposition.—By far the greater part of this formation was deposited near or along the shore in shallow water. The several conglomerate horizons in the lower half indicate the advance of the sea over a surface on which much debris had accumulated. The large proportion of arkosic quartzite affords evidence that mechanical disintegration preponderated over decay in the weathering of the exposed rocks. The many shale beds suggest periods of deposition in deeper water or more complete decomposition of the land surface, owing probably to a low relief. Calcareous material is very subordinate in amount in the sediments, and where it is present the bulk of the rock is sand or shale. The clear waters necessary for the deposition of limestone were not present as in the older Paleozoic sea.

Age.—Since no fossils have been found in this formation its age is undetermined. An attempted correlation with formations of other districts, based on lithologic character and stratigraphic position, would be but little better than a guess. Excepting the color, it is lithologically similar to the Rico and Cutler[1] formations of the San Juan region and to the upper division of the Maroon[2] conglomerate of the Crested Butte quadrangle.

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[1] U. S. Geol. Survey, Folios 120, 130, 131, 153.
Cross, W., and Howe, E., The Red Beds of southwestern Colorado: Bull Geol. Soc. America, vol. 16, 1905, pp. 447-498.

[2] Folio 9, U. S. Geol. Survey

It is not improbable that the original sediments were at least in part reddish, as suggested by the quantity of secondary biotite in some of the beds and by the red sandstone inclosed by the volcanic breccia north of Clover Mountain. It has been observed that where the Maroon formation has been metamorphosed[1] the rocks have lost their red color and become greenish.

The stratigraphic position with reference to the underlying Pennsylvanian sediments and the similarity to the Maroon conglomerate, taken with the geographic position, are the reasons for doubtfully referring the Kangaroo formation to the Permo-Pennsylvanian.

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[1]Folio 9, U. S. Geol. Survey.

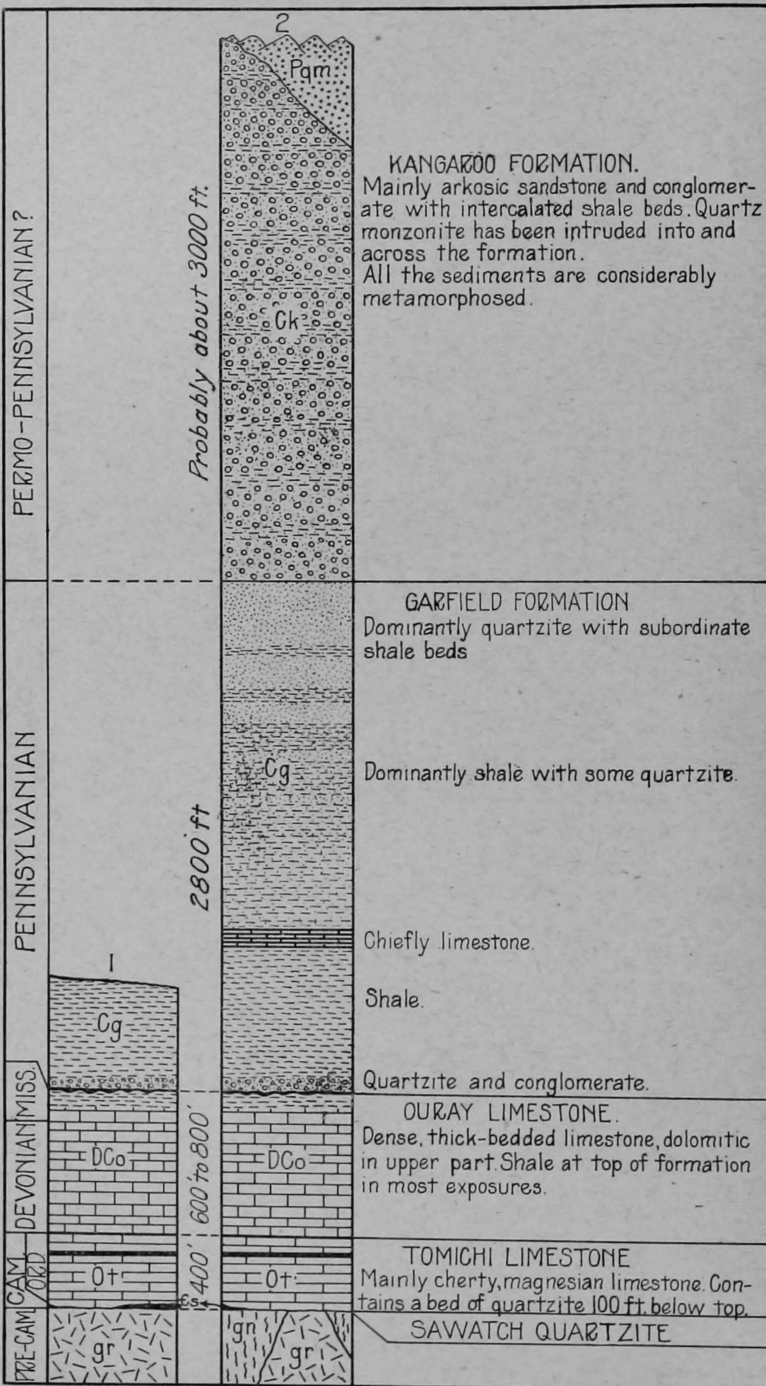

Figure 2.—Vertical sections of the Paleozoic formations in the Monarch and Tomichi districts. 1, section in Tomichi district; 2, section in Monarch district.

CHAPTER V

POST-CARBONIFEROUS IGNEOUS ROCKS

For the convenience of miners, mining engineers, geologists, and other field-workers, a description of the megascopic characters of each of the post-Carboniferous igneous rocks is given in this chapter. Definitions are included for those who have had no training in petrography. More detailed descriptions, together with notes on occurrence and age relations, are given in the chapter on petrography.

AGE

Except the monzonitic variety of quartz diorite in the stock near Monarch, all the rocks described in this chapter are shown by field relations to be younger than the early Paleozoic sediments, and nearly all are demonstrably younger than the youngest Paleozoic strata of the region. They are intrusive in and have cut through all the Paleozoic beds which have, as a consequence, undergone much contact metamorphism. Since the youngest determined Pennsylvanian beds are overlain by 5,000 feet of sediments which are probably in part Permian the igneous rocks may, with reasonable certainty, be considered post-Carboniferous. The quartz diorite of the Monarch and Tomichi districts is one of the oldest, if not the oldest, of the post-Carboniferous rocks here considered. This is very similar to the diorite of the Elk Mountains, which, according to Cross,[1] penetrates the Montana Cretaceous strata in the form of a stock. Emmons[2] shows that the Elk Mountain intrusives are of post-Laramie age. It is therefore probable that the oldest post-Carboniferous intrusions of the Monarch and Tomichi districts are not younger than post-Cretaceous. It is not improbable that most of the minor intrusions of the region are very much younger than the earliest post-Carboniferous plutonic rocks. Certainly the extrusive rocks on Vulcan and Central mountains bear evi-

[1] U. S. Geol. Survey, Folio 9, p. 4.
[2] U. S. Geol. Survey, Folio 9.

dence of being erupted after erosion had removed much of the probably thick, original cover of the plutonic intrusions.

The relative age of each of the important rock types, in so far as has been determined, is stated in the chapter on petrography.

QUARTZ DIORITE

Definition.—Diorite is a granular igneous rock composed essentially of soda-lime feldspar and one or more dark minerals of the mica, amphibole, and pyroxene groups. The soda-lime feldspar is most commonly andesine or labradorite, and usually exceeds the dark minerals in amount. If the diorite carries several per cent of quartz, usually accompanied by considerable orthoclase and biotite, it is called quartz diorite. With increasing orthoclase, the quartz diorites grade toward the quartz monzonites. In this paper only those rocks whose orthoclase is less than one-third the total feldspar present, are classed as quartz diorites.[1]

Occurrence and description.—Typical quartz diorite is found in a stock on the southeast slope of Lost Mountain and in a smaller stock on the southwest slope of Mount Stella. A rock which contains a larger proportion of orthoclase and less quartz, and hence more monzonitic, forms a small stock about a mile from Monarch toward the northwest.

The fresh quartz diorite of Lost Mountain and Mount Stella is dark bluish-gray, while weathered surfaces are a dull brownish-gray. The rock is fine-grained, but the unaided eye can readily detect abundant feldspar and numerous bright cleavage faces of black mica. The total amount of dark minerals which, as the microscope shows, include augite and hornblende, is greater than that of any other post-Carboniferous rock in the region. The grains have an average diameter of not more than one-sixteenth of an inch.

The monzcnitic variety, near Monarch, is lighter in color and somewhat coarser in texture than the Lost Mountain quartz diorite. In this rock also the unaided eye can readily recognize a large proportion of white to gray feldspar and numerous cleavage faces of black mica. With the aid of a lens fine parallel lines may be seen on some of the feldspar cleavage faces. The lines are caused by repeated twinning of the crystals and never

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[1] See Barrell, Joseph, Geology of the Marysville mining district, Montana: Prof. Paper U. S. Geol. Survey No. 57, 1907, p. 54.

occur in orthoclase. Their presence is the best criterion for the determination of plagioclase in the field. The microscope shows that this rock is very similar in composition to the "Salida granite" (monzonite) which is extensively quarried at Salida for building-stone.

In a small area near the west border of the Monarch stock the rock is mottled with alternating light pink and dark greenish-gray patches. The dark patches are segregations of the dark minerals and plagioclase, while the pink ones are composed principally of orthoclase and quartz.

QUARTZ MONZONITE GNEISS

Definition.—The name quartz monzonite was used by Brögger[1] for granular acid rocks between granites and quartz diorites in composition. Brögger's typical acid quartz monzonite, or adamellite, was evidently characterized by approximately equal amounts of orthoclase and plagioclase, with considerable quartz and subordinate mica, amphibole, or pyroxene. The name has been used in America in recent years to include rocks which have plagioclase much in excess of orthoclase. In this paper only those rocks whose feldspar is at least one-third orthoclase and whose plagioclase is one of the soda-lime series, are included in the quartz monzonite family. Acid rocks, whose feldspar is exclusively alkalic, even though half of it may be plagioclase (albite), are here placed in the granite class. Since many quartz monzonites can be distinguished from granites only by microscopic study of thin sections, in the field they may be conveniently called granites. Quartz monzonite gneiss is a granular rock that has the composition of quartz monzonite and a pronounced gneissic structure.

Occurrence and description.—The quartz monzonite gneiss is exposed throughout a long and narrow area east of Shavano Mountain and over a larger area northeast of Mount Etna. A small body of what is probably a less acid facies of this rock may be seen on the northeast slope of Clover Mountain. Smaller masses are found, in various parts of the area mapped, as inclusions, or xenoliths, in the later igneous rocks. On the southwest slope of Calico Mountain a remnant of sedimentary rocks is in contact with a small body of the intrusive gneiss.

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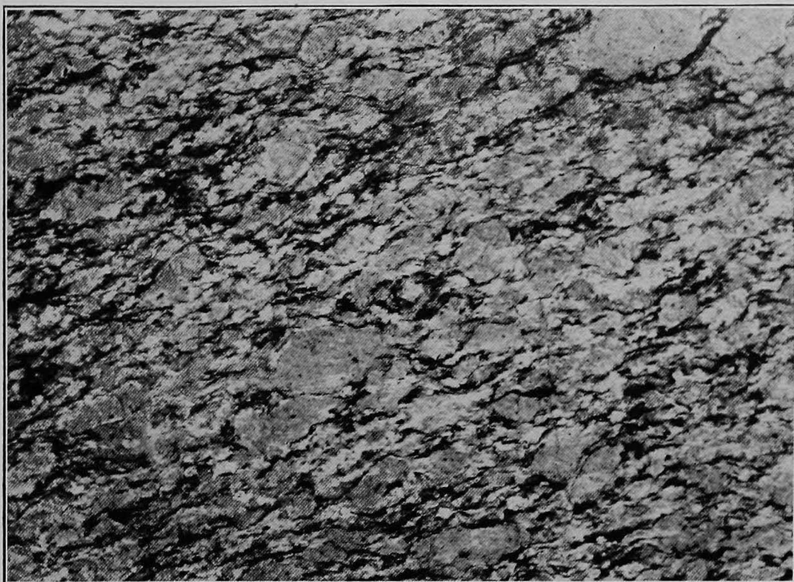
[1] Brögger, W. C., Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, pp. 58-64.

In the general area in which the gneiss is found it is the oldest post-Carboniferous rock now exposed. It was intruded as a stock which has evidently since been split and dissected by intrusions of quartz monzonite and other rocks.

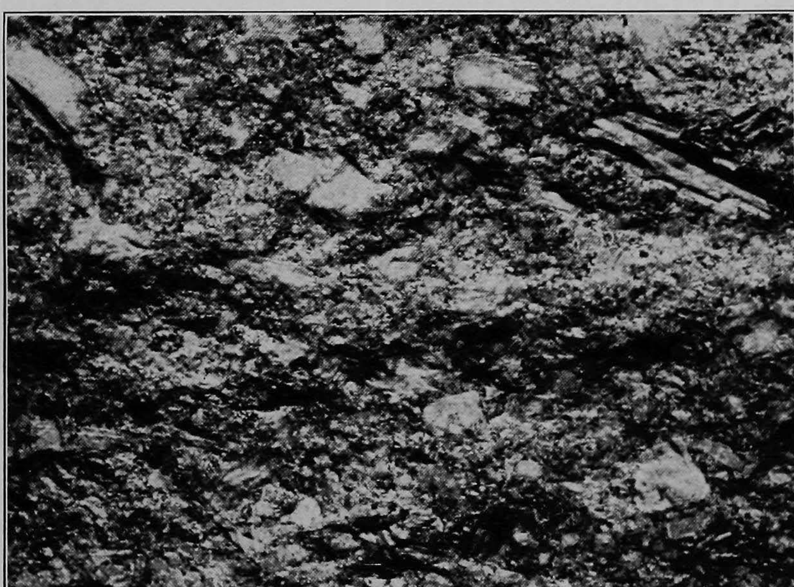
The gneiss is very coarse-grained, and almost uniformly shows a lenticular or foliated texture (Pl. XI). The naked eye readily recognizes feldspar, quartz, and biotite. The lenses, which range from a fraction of an inch to two inches, or more, in diameter, are commonly composed of a granular aggregate of quartz and feldspar. However, a single crystal of feldspar may be lenticular in outline because of having been pinched at the extremities. Occasional crystals of feldspar two to three inches long have escaped crushing. These are distinguishable by their uniform reflection of light from fresh cleavage faces. A few crystals are twinned, and the light is reflected to the eye from only half the crystal at once. The biotite, which forms but a small fraction of the rock, is segregated in bands and bunches.

PRINCETON QUARTZ MONZONITE

Name and occurrence.—Since there are two types of quartz monzonite in the region considered, it is necessary to give each, in this bulletin, a distinctive name for purposes of reference. The most abundant post-Carboniferous igneous rock in these districts is the quartz monzonite composing most of the batholith which is mainly north of the area surveyed. Since this type makes up the bulk of Mount Princeton, which is north of the mapped area, it is here called the Princeton quartz monzonite, while the batholith itself will be designated the Princeton batholith. This quartz monzonite is exposed throughout a large area north of the mapped region and extends southward into both the Monarch and Tomichi districts. The typical and reasonably fresh rock may be seen in the vicinity of Whitepine, on Taylor and Shavano mountains, and in Jennings Gulch. Several small stocks of the same quartz monzonite are found in the vicinity of Taylor Mountain and Cree Camp, while a larger one is exposed about a mile southwest of Clover Mountain. The Princeton quartz monzonite was intruded after the quartz diorite and quartz monzonite gneiss had crystallized, and is probably also younger than the Pomeroy type of quartz monzonite. The largest body of quartz monzonite in the Monarch district is dike-like in form, and is really an apophysis of the Princeton batholith. This dike-like mass seems to have been intruded at the



A.—QUARTZ MONZONITE GNEISS
About one-fourth natural size.



B.—ETNA QUARTZ MONZONITE PORPHYRY
About three-fourths natural size.

border of the gneiss stock near its southwest extremity, but in the vicinity of Shavano Mountain it has cut through the gneiss stock.

Description.—The Princeton quartz monzonite is commonly light gray both on weathered surfaces and fresh fractures. In the Tomichi district, however, particularly west and northwest of Whitepine, fresh fracture faces are commonly a bluish-gray, owing to the presence of a large proportion of plagioclase of this color.

The grain is medium to coarse and quite uniform except for an occasional pink feldspar phenocryst with a maximum diameter of about one inch. Feldspar, quartz, biotite, hornblende, and titanite can be seen with the naked eye in almost every specimen. The feldspar can be distinguished from quartz by means of the cleavage faces. Twinning striæ can sometimes be seen on the plagioclase cleavage faces, while the simple Carlsbad twinning, like that in the feldspar crystals of the gneiss, is found in both orthoclase and plagioclase. In some places both the orthoclase and plagioclase are white. In others the orthoclase has a pink tone, while the plagioclase is white or bluish. The hornblende can usually be distinguished from the biotite by means of its duller luster and less perfect cleavage. The titanite is honey-yellow in color and is in very small, well-shaped crystals sparingly scattered through the rock.

Throughout the greater part of the Chalk Creek district this rock, in so far as it has been observed, does not differ greatly from the quartz monzonite of the Monarch district. However, in Grizzly and Pomeroy gulches the rock becomes more granitic in composition near the southeast border of the batholith.

POMEROY QUARTZ MONZONITE

The Pomeroy quartz monzonite, so called in order to distinguish it from the Princeton type, is exposed over a large area in the northwest part of the Monarch district and adjacent part of the Chalk Creek district; Pomeroy Mountain is almost entirely formed of this rock. The same exposure continues to the Tomichi district, where it is found as a narrow strip on the west slope of Van Wirt Mountain. A large inclusion of the same rock is found in the granite in Browns Gulch. It is probable that this detached mass was separated from the larger body by the granite intrusion.

The rock is pinkish-gray to bluish-gray, and carries a great number of small, bluish-gray plagioclase crystals which frequently show twin striations on lustrous cleavage faces. In the hand specimen may also be seen pinkish to white orthoclase, chloritized hornblende, a few biotite crystals, and occasional pyrite grains. With the aid of a strong lens quartz may be seen intergrown with the orthoclase. Near the east border of the larger area the rock is finer in texture, decidedly porphyritic, and carries a larger proportion of quartz. Along the east border also, wherever this porphyry is exposed on the ridges, as at Pomeroy Pass, it is much stained by red and brown oxides of iron.

GRANITE

Definition.—Granite is a granular igneous rock whose characteristic minerals are alkali feldspar and quartz. These minerals are commonly accompanied by soda-lime feldspar, mica or amphibole, and more rarely by a pyroxene. The name was formerly used for some rocks that are now classed with the quartz monzonites and quartz diorites, and it is still so used, at times, as a field name for these rocks.

Occurrence and description.—The post-Carboniferous granite forms a stock which extends from the south side of Browns Gulch northward about two miles to White Mountain, and possibly farther. A smaller stock is found on the south slope of Shavano Mountain.

The rock is almost uniformly coarse in texture, and contains white feldspar with sometimes a pink tinge, quartz, and biotite which can be readily determined with the naked eye. Feldspar makes up nearly two-thirds of the rock and quartz nearly one-third, while biotite is almost negligible in quantity. The granite is practically white, and may be seen from a long distance. In water-courses and on gentler slopes fragments of the disintegrated granite form a white bed which is almost blinding in the sunlight.

On White Mountain miarolitic cavities in this granite have furnished a variety of gem minerals, including aquamarine, topaz, and phenacite.

ETNA QUARTZ MONZONITE PORPHYRY

Definition and name.—A porphyry is an igneous rock that contains well-shaped crystals (phenocrysts) of one or more minerals in a finer-grained or incompletely crystallized matrix (groundmass). A porphyry which has the mineral composition of quartz monzonite and whose phenocrysts make up about half the rock or more, is called quartz monzonite porphyry. In order to distinguish the commonest type of quartz monzonite porphyry of the Monarch and Tomichi districts from the other varieties present, it is here called Etna quartz monzonite porphyry because it is abundant on the top and slopes of Mount Etna.

Occurrence.—The Etna type of quartz monzonite porphyry occurs in two stocks and in a few dikes. The stock which cuts the quartz latite body described below, extends from the west slope of Monumental Mountain to the north slope of Mount Etna. A smaller stock is found northeast of Tomichi. The longest dike reaches from the west slope of Clover Mountain to the margin of Browns Gulch. At the Condor mine this dike is nearly 300 feet wide, but it narrows to fourteen feet about 800 feet northeast of the mine and widens again to 500 or 600 feet east of Jennings Gulch. Several smaller dikes are exposed in both the Monarch and Tomichi districts.

Description.—This porphyry is characterized by the numerous large orthoclase phenocrysts from half an inch to two inches in length (Pl. XI). North of North Fork where erosion is rapid, these phenocrysts in parts of the dike are bluish, but elsewhere they are commonly pink to brownish. The pink phenocrysts remind one of the large orthoclase phenocrysts of the Lincoln porphyry of Leadville, but the groundmass of the Etna porphyry has a much coarser grain than that of the Leadville rock. A few of the orthoclase crystals are twinned according to the Carlsbad law.

Less conspicuous, but still of considerable size, are phenocrysts of white to bluish plagioclase, quartz, hornblende, and biotite. Many of the plagioclase crystals show twinning striæ and some show Carlsbad twins in addition. The hornblende and biotite phenocrysts are the smallest in the rock. Occasional small, well-shaped crystals of yellow titanite are found both among the smallest phenocrysts and inclosed by the large orthoclase crystals.

In the hand specimen the aggregate of quartz, plagioclase, hornblende, and biotite might be considered the groundmass in which the orthoclase crystals, as phenocrysts, are embedded. But the microscope shows, in addition, a considerable residue cementing all the crystals named. This residue, which constitutes the groundmass proper, is composed essentially of fine-granular orthoclase and quartz, with small amounts of plagioclase, hornblende, and biotite. The microscope also shows that all the crystals seen with the naked eye belong to one general period of development and that the naked eye, therefore, detects no true groundmass.

This rock is sometimes locally called granite, and in a field classification neither the name granite nor granite porphyry would be inapplicable.

OTHER VARIETIES OF PORPHYRY IN STOCKS

The dike-like stock near the head of Tomichi Creek is composed partly of porphyry very similar to the Etna type, but mainly of a variety containing smaller phenocrysts and a greater proportion of groundmass. On the north slope of Contact Hill and just north of Bonanza Creek are small exposures of a type which is similar to the Etna type in composition and intermediate between the Etna porphyry and the rhyolite porphyry in texture.

About a mile and a half northwest of Shavano Mountain is a small area which shows two varieties of porphyry. One is similar in composition to the Princeton quartz monzonite; it shows small, bluish plagioclase phenocrysts and a few biotite crystals in a groundmass of orthoclase and quartz. The other variety is a granite porphyry having a few small phenocrysts of biotite and acid plagioclase in a microgranitic groundmass composed chiefly of quartz and orthoclase.

ANDESITE

Definition.—Andesites are dense igneous rocks composed essentially of soda-lime feldspar and hornblende, biotite, or pyroxene. A small amount of orthoclase is often present, in addition to free silica either in the form of quartz or glass. Most andesites are porphyritic, containing small phenocrysts of plagioclase and one or more dark minerals, in a dense groundmass.

Occurrence and description.—In the Monarch district andesite is found throughout an area which reaches from Mount Etna to Browns Gulch and is more than a mile in average width. The freshest rock is dark gray and has a dense groundmass which greatly exceeds the phenocrysts in volume. A few small phenocrysts of plagioclase and biotite can be seen in the hand specimen. The microscope shows also the presence of hornblende crystals. Pyrite grains are not uncommon in joint-planes. The rock is commonly greenish on account of the presence of much epidote. Weathered surfaces are frequently red or brown, owing to the oxidation of the iron of the dark minerals to hematite or to limonite. These colors are very conspicuous on Calico Mountain.

QUARTZ LATITE PORPHYRY

Definition.—Quartz latite porphyry is here taken as a dense porphyry, which has essentially the chemical composition of quartz monzonite and, in so far as it may be crystallized, the mineral composition of quartz monzonite. It differs from quartz monzonite porphyry in having a denser groundmass and greater proportion of groundmass. As a rule, the phenocrysts of quartz latite porphyry are smaller than those of quartz monzonite porphyry.

Occurrence and description.—This porphyry is found in considerable volume on the slopes of Mount Etna and Monumental Mountain and in the vicinity of Chalk Creek Pass. In addition to the several bodies mapped there is a considerable body on the southwest slope of Mount Etna, which was cut by the Macedonian tunnel. The boundaries of this could not be accurately traced owing to the large amount of slide-rock. It is very probable that all these detached bodies once formed part of a single mass which was later dissected by the Etna porphyry intrusion.

The rock is bluish-gray and carries numerous small phenocrysts of white to bluish plagioclase, a few pink feldspars, numerous biotite and hornblende phenocrysts, and occasional small, yellow titanite crystals. The groundmass, which is approximately equal to phenocrysts in volume, is very dense and is shown by the microscope to contain a small amount of uncrystallized material. The character of the groundmass and the composition of the rock, as determined chemically and microscopically, make the local name "diorite porphyry" inapplicable to this rock in a strict petrographic classification.

DIKE-ROCKS

In addition to the strong dike of Etna porphyry mentioned, there are many smaller dikes of porphyry of several interrelated types and varieties. These dikes are, in part at least, the latest intrusions of the region, and cut nearly all the older rocks. They are especially abundant in the Monarch district, near the south and southeast margins of the Princeton quartz monzonite. In the sedimentary rocks, some intrusions which cut across the strata as dikes through most of their course, in places follow the bedding as intrusive sheets for considerable distances. Although there are several variations from the types, the dike-rocks include the following: monzonite porphyry, quartz monzonite porphyry, latite, latite porphyry, quartz latite porphyry, andesite porphyry, rhyolite, rhyolite porphyry, and pitchstone porphyry.

MONZONITE PORPHYRY

Monzonite porphyry is composed essentially of orthoclase and plagioclase, in about equal amounts, and one or more dark minerals of the mica, amphibole, and pyroxene groups. In volume the phenocrysts commonly equal or exceed the groundmass.

Dikes of monzonite porphyry are most common near the head of Taylor Gulch and on the slopes of Taylor Mountain. An unusual variety of this rock, composed almost entirely of small phenocrysts and a negligible quantity of groundmass, is found in a dike about a mile southwest of Maysville.

The ordinary type of monzonite porphyry in the region mapped is bluish-gray and generally carries phenocrysts of orthoclase, plagioclase, and hornblende in a dense groundmass. The phenocrysts commonly make up about half the rock mass and are for the most part less than a quarter of an inch in diameter. A few dikes carry biotite instead of hornblende, while others carry both biotite and hornblende. Locally, cubes or grains of pyrite are abundant. Flow-structure is shown in several dikes by the parallel orientation of the hornblende crystals. In several places secondary epidote gives a greenish color to the rock.

QUARTZ MONZONITE PORPHYRY

Narrow dikes of this rock are most common in and near the quartz monzonite in the Monarch district.

The quartz monzonite porphyry occurring in narrow dikes differs from the Etna porphyry in having a finer texture generally, considerable variation in the quantity of quartz, hornblende, and biotite, and a generally smaller proportion of orthoclase phenocrysts. In texture and color the rock is similar to the quartzless monzonite porphyry. Quartz phenocrysts may be numerous to rare, or even absent. When the quartz of this porphyry is absent as a phenocryst, it is confined to the groundmass, and hand specimens of the rock closely resemble those of the quartzless monzonite porphyry. Although pink orthoclase phenocrysts are not so common as in the Etna porphyry, the microscope shows a large proportion of orthoclase in the groundmass.

LATITE

Latite, which is the dense equivalent of monzonite or monzonite porphyry, occurs in comparatively few dikes. These are chiefly on Taylor Mountain and in the general region west of Boss Lake.

The latite is commonly a light gray to white felsitic rock, with few or no megascopic phenocrysts. The phenocrysts that are present are small, and are chiefly feldspar with subordinate biotite or hornblende. Small cubes of pyrite are locally abundant.

This rock differs from rhyolite chiefly in that it typically has no quartz and contains orthoclase and plagioclase in approximately equal amounts. The true mineral composition is determinable only under a high-power microscope. In the field a rock of this character is commonly called felsite.

LATITE PORPHYRY

This rock has the same composition as monzonite porphyry and latite, and in texture is intermediate between them. In the region surveyed most of the latite porphyry is very similar to the monzonite porphyry in texture and composition, but has smaller phenocrysts and more finely crystallized groundmass.

QUARTZ LATITE PORPHYRY

This rock was observed in only two dikes. One of these crosses the divide northeast of the head of Jennings Gulch; the other is crossed by the road about half a mile west of the Victor mine in the Tomichi district. The quartz latite porphyry of these dikes is practically identical with that near the head of Middle Fork and needs no further description.

ANDESITE PORPHYRY

Only a few dikes of andesite porphyry are found in the area mapped. One of the most typical is just east of Boss Lake; another is on the north slope of Contact Hill in the Tomichi district. This porphyry is greenish-gray and carries many small crystals of plagioclase and hornblende, besides a few flakes of biotite, in a dense groundmass.

RHYOLITE

Rhyolite is a dense igneous rock having approximately the same chemical composition as a granite and essentially the mineral composition of a granite, in so far as it may be crystalline.

The most typical rhyolite found in the area mapped is on the east slope of Taylor Mountain. It is white and dense and closely resembles the felsitic latite in appearance. It differs from the latite in that its feldspar is dominantly orthoclase, and also by the presence of quartz, either as small phenocrysts or as microscopic grains and patches in the groundmass.

RHYOLITE PORPHYRY

Rhyolite porphyry has the same mineral and chemical composition as rhyolite, but carries abundant phenocrysts.

Typical rhyolite porphyry occurs in an intrusive sheet east of the David H. mine and in a dike cut by the Parole tunnel. This dike can be traced for a considerable distance in and near the Morning Glim fault. The weathered rhyolite porphyry is commonly light gray or white and carries, in a felsitic groundmass, quartz and feldspar phenocrysts up to three-eighths of an inch in diameter. Fresher material from the Parole tunnel shows small biotite phenocrysts in addition to quartz and feldspar, and is dark gray in color.

PITCHSTONE PORPHYRY

Pitchstone is natural glass with a resinous luster. It is formed by the sudden cooling of rock magma which usually has nearly the chemical composition of granite but contains more water, 5 to 8 per cent. Pitchstone which carries numerous phenocrysts is called pitchstone porphyry.

Pitchstone porphyry occurs on the border of a rhyolite porphyry dike in the Morning Star mine and in several short tunnels near West Point in the Tomichi district. A row of prospect holes on the northwest slope of Lake Hill has encountered a similar dike.

The pitchstone porphyry of the Tomichi district is commonly green, yet a brown variety was found on at least one dump near the Morning Star mine. Although the glassy groundmass greatly exceeds the phenocrysts in volume, small crystals of feldspar, quartz, and biotite are common.

VOLCANIC BRECCIA

Volcanic breccia owes its formation to explosive volcanic action; it contains numerous angular fragments cemented by a matrix which is principally lava or tuff. The fragments are in part lapilli and bombs thrown out by explosions, but they are also very likely to be in large part formed by the shattering of the rock which forms the walls of the volcanic vent. Volcanic breccia is exposed on the top and slopes of Vulcan Mountain. Small exposures are found on the south shoulder of Central Mountain and in Fort Scott Gulch.

This breccia carries angular fragments of granite, quartzite, arkose, chert, limestone, baked shale, and quartz monzonite gneiss, besides material too badly weathered for identification. The greater number of fragments range from a quarter of an inch to two inches in size. The matrix, which is generally greenish-gray, is shown by the microscope to be composed chiefly of shreds and fragments of glass.

FLOW BRECCIA

The flow-breccia which caps Brittle Silver Mountain, contains numerous small, angular fragments of feldspar and dark gray-brown porphyry, in addition to a few fragments of quartz, in a light-gray matrix. Many of the fragments are more or less lenticular in form and lie with their longest diameters in the direction in which the magma was flowing when it began to solidify.

The microscope shows that the matrix is made up chiefly of glass and is generally stringy or ropy. After the magma was extruded the flow evidently continued during at least a part of the period of rapid solidification.

CHAPTER VI

STRUCTURAL GEOLOGY

Owing to the scarcity of extensive underground workings and the abundance of talus and drift, the details of geologic structure of the region have not been worked out as fully as desirable, but many of these details, as well as important general features, have been determined. To the explanation of the pre-Cambrian regional metamorphism in which some of the rocks of these districts shared, the writer can contribute nothing. The processes of Paleozoic sedimentation and accompanying crustal oscillations as recorded by the sedimentary rocks in this region have already been briefly treated. Aside from the ore deposits, which will be separately described, the principal remaining factors to be considered in the structural geology of the region considered are folding and faulting, jointing, solution, and igneous intrusion, including contact metamorphism.

FOLDING AND FAULTING

The Paleozoic strata, in their attitude, interrelations, and relations toward older rocks, furnish the only criteria by means of which the principal folding and faulting of the region may be worked out. Since these strata cover only a small part of the region and have in many places been dissected by igneous intrusion, many important details of the folding and faulting cannot be determined with certainty.

FOLDS

An approximately east-west line through Monarch Hill would cross five synclinal folds within the area mapped. These are, respectively, on the southeast slope of Lake Hill, on the northwest slope of Monarch Hill, southeast of Garfield, southwest of Maysville, and southeast of Maysville. The synclinal fold southeast of Garfield and another near Cree Camp are really minor folds which merge into the much larger syncline whose south extremity is on Monarch Hill.

The west limb of this syncline, a large part of which is faulted off on Syncline Hill, was probably once continuous with the eastward-dipping sediments on Clover Mountain and north of Fort Scott Creek. Between the last two outcrops mentioned are other outcrops of eastward-dipping limestone overlying the pre-Cambrian granite. All these, together with the west border of limestone on Monarch Hill, are nearly in a straight line. The exposures on Syncline Hill and north of Middle Fork show that the total thickness of sediments involved in this syncline was so great that the west border of the west limb must have been nearly as far west as the top of Clover Mountain if the strata were nearly vertical. If dipping at an angle of 40° to 60° the west limb would extend west of the present divide. In this position and with an eastward dip the Ordovician limestone is now found. Further evidence that the strata of Taylor Gulch and those west of the divide once formed part of a single syncline is furnished by the large body of limestone and quartzite on the divide, and by the masses of arkose in the volcanic breccia of Vulcan Mountain. This arkose is evidently the unmetamorphosed equivalent of part of the Kangaroo formation, or it is a younger deposit not now elsewhere seen in the region.

In the Tomichi district most of the sediments dip toward the east. Significant exceptions are found in the westward dip of the strata near the head of Noname Creek and of a remnant of Ordovician limestone on the south shoulder of Central Mountain. It is probable that these two widely separated outcrops of westward-dipping strata represent the east limb of a syncline whose west limb is found partly on Lake Hill, West Point, and Porcupine Ridge, and partly near the northwest corner of the Tomichi district. A large part of this limb, faulted off, is seen in the eastward-dipping sediments just west of the northwest portion of the area mapped, where they are partly in fault contact with the pre-Cambrian granite and partly in eruptive contact with the quartz monzonite.

There is no reason to doubt that an anticline once connected the Tomichi syncline with the Monarch syncline except where the strata were greatly faulted. A small remnant of the strata involved in the anticline is found on the divide northeast of the head of Noname Creek. The axis of the anticline perhaps passed not far east of this remnant and through or near the present position of Central Mountain.

The proximity of the outcrops of strata of evidently opposite limbs of the anticline on Central Mountain and north of Fort Scott Creek, and the attitude of these strata suggest that in this vicinity the anticlinal folding was much less pronounced than the folding in many other parts of the region. It is not improbable that the Monarch and Tomichi synclines, like the echelon synclines of the Monarch district, merged into one large fold farther north. On the west slope of the Sawatch Range, near the crest, about ten miles north of Whitepine, is a thick series of sedimentary rocks dipping eastward, that is, toward the divide. Whether these beds are cut off by a fault or by an intrusion has not been determined.

AMOUNT OF TILTING

The strata have been tilted through an angle which ranges from a few degrees to 90°, and even more in several places. Most of the sediments of the Tomichi district have a dip between 20° and 50°, being generally higher in the north part than in the south part of the district.

The beds of the Monarch district show a much greater range in dip. Near Maysville the dip varies from a few degrees to 65°. The dip of the southeast limb of the fold on Monarch Hill ranges from 30° to 45° for the most part. However, in a drift from the Madonna No. 6 level, toward the west, along the granite-limestone contact, the granite wall is vertical for a considerable distance and in at least one place dips a few degrees from the vertical toward the south. Again, the same contact at the top of the stope in the Hawkeye mine has been tilted through an angle of a little more than 90°. East and north of Garfield the strata are nearly vertical. In the Lilly mine the granite floor on which the sediments were laid down now stands vertical or but slightly inclined from vertical toward the west. In the Garfield tunnel, driven northward along the granite-limestone contact from the creek below Garfield, the dip near the portal is toward the west, but near the breast the granite forms the hanging wall with an eastward dip of 73°. Similar overturns are found in Kangaroo Gulch.

The most notable overturn in the district occurs on Monarch Hill where it can be well seen in the Hawkeye mine. The Hawkeye tunnel was driven several hundred feet to the granite-limestone contact and thence along the contact where the granite forms the hanging wall with a westward dip of 40° to 60°. In

SYNCLINE HILL

the upper part of an upraise from the end of the main tunnel the granite hanging wall dips westward 25°. A crosscut to the east limb of the syncline found the granite footwall dipping westward 28°. In the Madonna No. 6 tunnel the quartzite of the west limb of the fold dips 60° N. 53° W. The same quartzite exposed in a drift from the Monarch Contact tunnel dips westward 50° to 60°.

It is readily seen that only strong compressive forces could have caused the folding which has been noted.

FAULTS

Local faults of small throw are numerous in the mines in all parts of the sedimentary area in the Monarch district. The Tomichi district affords few opportunities for underground study, but it is probable that faulting is as common here as in the Monarch district. The local faulting was accompanied by movement in many directions, as evidenced by the slickensided surfaces.

The larger faults whose position could be accurately determined are shown on the map in solid lines; those whose exact position could not be determined are represented by dashes. Nearly all the larger faults are thrust faults and were in all probability produced in part by the stresses which caused the folding.

Though many of the faults show a comparatively small throw they are important in that they provided channels for the circulation of mineral solutions; the crushing of the rock, which accompanied the faulting in many places, furnished open ground favorable to ore deposition. For these reasons not only will the proved faults be described in considerable detail in the following paragraphs, but indications of other faults will be noted in the hope that they may receive attention from prospectors and mining engineers in the development of the region. Had time permitted more detailed study the field party would probably have demonstrated the existence of a few faults now only suspected, but many can be certainly disclosed only by underground work.

LAKE FAULT

This thrust fault, which passes under Boss Lake and trends southward an undetermined distance from the contact between the granite and quartz monzonite, shows a greater displacement than any other fault in the region. The Monarch Contact tunnel, driven N. 37° W. from the portal, encountered this fault at 117 feet. In July, 1912, the tunnel had been driven along the fault 477 feet. The course is a few degrees east of north for the greater part of the distance, but the tunnel bears about N. 5° W. for the last 175 feet. Where first encountered, the granite hanging wall dips westward about 80°, but near the breast of the tunnel the same wall dips westward 56°.

Development work done in this tunnel shows that the fault is about fifty feet west of the "parting quartzite" near the portal and 100 feet west of the same quartzite 500 feet north of the portal. This indicates that the fault has cut out some of the limestone and crosses the strike of the beds at an acute angle. It is possible that the limestone between the fault and the quartzite widens for some distance ahead of the breast of the tunnel, but the fault doubtless cuts off the quartzite somewhere between the present workings and the saddle on Syncline Hill. According to field measurements and calculations the Paleozoic sediments on Syncline Hill are about 4,500 feet thick. Since the thrust has raised the granite west of the fault nearly to the level of the youngest sediments on Syncline Hill the throw is at least 4,000 feet. To this estimate may be added the thickness of the granite which has been removed by erosion since the removal of all the sediments west of the fault. The displacement along this fault is greater than the throw since the fault is not vertical.

South of the Monarch Contact tunnel the fault is concealed by glacial deposits. It may possibly trend toward the head of the south branch of South Fork; the approximate straightness of the valley southward from Monarch in inherently structureless granite suggests that it may follow the line of a fault. There is also a possibility, unsupported by convincing evidence, that the Lake fault is continuous with the Madonna fault. More probably, however, the Lake fault passes by gradations into the overturned synclinal fold on the northwest slope of Monarch Hill.

MADONNA FAULT

This is a thrust fault hading toward the southwest—that is, with the upthrow on the southwest side. The displacement is well seen on the top of Monarch Hill, where the granite-limestone contact is offset about 500 feet. On the No. 6 level of the Madonna mine the offset is about 200 feet — that is, the granite extends about 200 feet farther northwest on the southwest side of the fault than it does on the northeast side. The strike of the fault on this level is N. 50° W. in and near the granite. The dip is toward the southwest a few degrees from vertical. It is reported that the granite wall 150 feet below the tunnel level is two sets (about twelve feet) farther southwest than at the level of the tunnel. The dip here is hence about 85° (hade 5°). On No. 6 level the fault-fissure in the granite is fifteen to twenty inches wide and filled with mineralized gouge.

On this level the trend of the main fault has not been determined with certainty where it passes away from the granite into the sedimentary rocks. The limestone and quartzite are dislocated and crushed in a number of places; relationships indicate that there has been branching of the fault. The most pronounced and regular break that has been followed in the development of the mine strikes about N. 25° W. If this is the main fault and if it holds the same strike as it passes northward the Madonna fault either intersects the Lake fault near the portal of the Monarch Contact tunnel or is continuous with the Lake fault. The latter alternative is improbable since the displacement on No. 6 level is much less than on the top of Monarch Hill and very much less than that of the fault on Syncline Hill, whereas, if it were one continuous fault, the displacement on No. 6 level would probably be greater than that on the top of Monarch Hill. If the Madonna fault continues northwestward with the same strike that it has in the granite it should intersect the Lake fault between the portal of No. 6 tunnel and the South Fork wagon-road, the point of intersection being dependent on the position of the Lake fault. Whatever may be the strike of the Madonna fault there is no reason to doubt that it meets the Lake fault.

MAYFLOWER FAULT

The Mayflower fault has been mapped chiefly from surface indications; the displacement was seen underground by the writer only in the Madonna No. 5 tunnel, in the Mayflower prospect tunnel a short distance above the portal of No. 5 tunnel, and probably in the Eclipse mine. In the Mayflower tunnel the fault strikes N. 50° W. and dips 70° southwest. Striations on the footwall pitch northwest about 15° from the vertical. These striations, of course, record only the latest movement. It is possible, though perhaps improbable, that the fault is a heave, or horizontal fault.

At the top of Monarch Hill the relations are those of a normal fault, that is, with the downthrow on the hanging-wall side. The black dolomite of the Ouray formation outcrops on the hillside northeast of the fault below the Mayflower tunnel but is not exposed southwest of the fault. This points to the probability that here the fault is an overthrust, though a normal fault farther southeast. Such relationships are found in rotary faults.

According to Mr. A. Eilers, who is familiar with the structure in the higher workings of the Madonna mine, the block between the Madonna and Mayflower faults has dropped through a vertical distance of 200 to 250 feet and is badly broken. There is no regularity in dip and strike and the bedding planes are not continuous.

OTHER FAULTS OF MONARCH HILL

On the sixth level of the Madonna mine a drift along the granite-limestone contact encountered a fault at about 250 feet northeast of the Madonna fault. The granite is thrown northwest on the southwest side of the fault, just as it is at the Madonna fault, but the amount of throw is unknown.

The largest developed ore-shoot of the Hawkeye mine follows a fault which may be seen in the granite footwall of the stope. In the present workings the displacement, which is measurable for only a short distance, does not exceed four feet, with the upthrow on the southwest side of the fault.

The Silent Friend No. 2 tunnel is driven approximately S. 70° E. for the first 500 feet. At 385 feet the granite was encountered in a short crosscut on the south side of the main tunnel, and but a few feet distant. This is evidently the floor on which the limestone was deposited; the contact dips about 50° N. 45° W., and shows no evidence of being a fault contact. The main tunnel follows a break for some distance, and in a few places granite may be seen either in the roof of the tunnel or on the south wall. About 300 feet due east of the point at which the granite was first uncovered a crosscut encountered the granite-limestone contact dipping about 50° N. 45° W. The evidence is strong that this offset is caused by a nearly vertical fault striking about N. 50° to 60° W. When allowance is made for the obliquity of the crosscut with reference to the strike of the contact, the offset is approximately 250 feet. Produced downward, this plane would nearly coincide with the plane of the

Hawkeye fault mentioned. When the surface geology was mapped no considerable displacement of the beds was noted above the apparent line of faulting in the mine, but a little mineralization is shown by prospect holes; in this region calcite and limonite are very common along fault planes.

There is good evidence of a fault near the south extremity of the syncline on Monarch Hill, but the trend could not be determined. Near the granite-limestone contact on the west limb of the same fold there has been much crushing of both granite and limestone, as seen in the Silent Friend No. 3 tunnel. Sheets of granite penetrate the limestone in a manner that suggests igneous intrusion, except that they have not been seen crosscutting the limestone.

It is probable that a fault striking northwest, between the Madonna and Mayflower faults, intersects the former fault at Zero level of the Madonna mine. The rock in the Stemwinder prospect tunnel in the steep ravine southeast of Monarch, is fractured and slickensided, but no decided fault has been observed here. A short distance north of the Black Tiger mine the relationships of granite and limestone on the dump from a tunnel now caved, point to a fault which is indicated on the map, though not proved.

FAULTS NEAR GARFIELD

Evidently the same strata as those quarried southwest of Garfield outcrop just north of the railway and west of the Taylor Gulch road. The beds in the two places mentioned do not have a greater difference in dip and strike than could be easily explained by the sharp fold. This great offset in beds with nearly the same dip and strike can be accounted for only by a fault having a displacement of several hundred feet. This fault, which is shown on the map, very probably passes a little west of the limestone outcrop north of the railway, where talus covers the bedrock, and through the badly broken limestone a short distance northeast of the quarry.

The fault shown on the map in dashes northeast of Garfield is plotted with less confidence than the quarry fault. Since, in most of its course at the surface, it cuts through shale more or less talus-covered, the exact position and amount of displacement cannot be determined at present.

Nearly a mile southeast of Garfield there are several small faults which cannot be represented on a map of small scale.

In addition, there is at least one fault of apparently considerable displacement, whose trend cannot be determined from surface indications. Much of the area is covered with talus, but a mile south of the railroad, in a caved prospect on the west limb of the syncline, the "parting quartzite" is found near the granite wall. From this point southward for several hundred yards the quartzite is not exposed while the limestone is exposed. It is possible that the granite has cut out the quartzite and some limestone by being faulted upward along a north-south line.

FAULTS OF TAYLOR GULCH

Although there is much evidence of faulting near the head of Taylor Gulch, the faults cannot be worked out from the surface indications alone, and the present underground workings do not afford many opportunities for studying the structural features.

In the Denver mine indications of faulting can be seen in the gouge and crushed rock, but the direction of movement is not evident. Since very little water flows on the surface in the gulch, even when the snows are melting most rapidly, it is not improbable that the gulch may be above a fault which furnishes a channel for the ground-water. The same conditions are found in a shallow and straight ravine heading high up on Taylor Mountain and trending southeast a little south of the Jewell tunnel. Further evidence of faulting along this line is the mineralization on the Last Chance and New York claims.

A fault with a throw of only a few feet can be seen on the steep north slope southwest of Cree Camp. The limestone is much broken and mineralized in the vicinity of the Song Bird mine. Not far east, blocks of granite on the dump of a prospect tunnel now caved, suggest the presence of granite much farther west than it would be if it had not been displaced by faulting.

MORNING GLIM FAULT

This name is here applied to the long fault in and near which are the Morning Glim mine workings. It can be readily traced from the head of Noname Creek to the contact between the granite and quartz monzonite northeast of Whitepine. The throw is equal to the thickness of the Paleozoic sediments of the Tomichi district plus the thickness of the granite eroded away northeast of the fault, and hence more than 1,000 feet.

When the Tomichi district was being mapped, this fault was not accessible underground, and consequently the average dip is unknown to the writer. There seems to be but little doubt, however, that the dip is in general toward the northeast and that the displacement is a thrust through most of its course. The general relations are conspicuous on the steep east slope west of the head of Noname Creek, where the outcropping Tomichi limestone, from the base to the "parting quartzite," abuts against the granite (Pl. XIII). The immediate break is covered with talus, but the dip appears to be toward the north at an angle of 60° to 70°. The granite, in its upward movement, has dragged the broken ends of the limestone strata up into a vertical, or even slightly overturned, position. The thickness of the beds involved in this drag is at least thirty feet. This folding is good evidence that the fault dips northward or at least that it does not dip southward. According to Mr. T. H. Jenks, of the Spar Copper Company, the dip of this fault in the Spar Copper mine is northeastward at an angle of about 60° (hade 30°).

STAR FAULT

A second important fault in the Tomichi district, here called the Star fault because in and near it are the North Star and Morning Star mines, may be traced from near the head of Spring Creek toward the northeast for half a mile or more. From surface indications this fault cannot be traced to the Morning Glim fault, but the displacement about half a mile distant is so great as to indicate, with strong probability, that it reaches the latter fault.

The Star fault dips toward the east as can be seen in the Morning Star and the Victor mines. It is hence a thrust fault since the upthrow is on the east side. The exact amount of dip is unknown, but a porphyry dike that follows the fault very closely, dips 65° eastward 200 feet below the surface in the Morning Star mine. If the dip be taken as 80° (hade 10°) and the beds continue downward with the same dip as shown in the outcrops the displacement is about 2,000 feet. The displacement is greater if the dip of the fault is the same as that of the dike.

OTHER FAULTS OF THE TOMICHI DISTRICT

The evidence for two parallel eastward-striking faults on West Point is so good that they are indicated on the map, although their existence cannot be proved without digging; talus covers the contact between the granite and Paleozoic strata as well as all the limestone of the faulted block below what is probably the "parting quartzite." If the faults do exist, a block nearly 200 feet wide has dropped down and caused an offset of about 150 feet. The evidence of these faults is given in the next paragraph.

A short distance northeast of the highest point in this vicinity is a shallow prospect hole in broken ground, having the "parting quartzite" on the south and marble on the north. For nearly 200 feet toward the north marble outcrops continuously, but no quartzite can be seen. At about 200 feet north of the prospect the marble abuts sharply against the broken end of the "parting quartzite" which can be traced continuously down the north slope. The fault cannot be traced in the coarse-grained marble below the quartzite toward the west although the outcrop is distinct for some distance. In view of the extreme contact metamorphism that the rocks in this vicinity have undergone, it does not seem unreasonable to suggest that the fracture may have been healed in the process of marmorosis. About 150 feet N. 70° W. of the prospect mentioned, an inclined shaft has been sunk in quartzite. This is probably the displaced "parting quartzite," and was so considered in indicating the faults on the map; but certain determination by surface indications is impossible, since the Sawatch quartzite is found a little farther north.

About 250 feet west of the west boundary of the area mapped, in the line of the geologic section A-A, the Paleozoic strata dip eastward toward the pre-Cambrian granite from which they are separated by a fault which strikes north. The throw is greater than the total thickness of the strata which are apparently about the equivalent of the strata displaced at the Morning Glim fault.

DIRECTION OF DEFORMING FORCES

It is evident from the character and trend of the folds that the region was compressed between major east-and-west forces which threw the sedimentary rocks into a series of synclines and anticlines. These forces were accompanied by less important north-and-south stresses which produced the echelon folding in the Monarch district. Since marine deposits are now found 12,500 feet above sea-level, it is obvious that vertical forces were also important. This is true whether it be assumed that the range has been forced upward or that the country on both sides of the range and, in a greater degree, the sea-bottom, have settled.

The faults were very probably produced, or at least initiated, by the same forces that effected the folding, being developed along planes in which the rocks were strained to the extent of rupture. The high dip of the fault-planes indicates that, in the faulting, differential vertical forces were predominant, while horizontal forces were subordinate. The strike of the faults indicates that the directions in which the opposing horizontal forces acted were in general east-northeast and west-southwest, respectively.

The Lake fault and Morning Glim fault have been described in previous pages as dipping toward each other, and are so represented in section C-C of Plate III. The block, therefore, between the two faults named, narrows downward, and certainly has been raised with reference to the blocks on the east and west sides. The elevation of a downward-narrowing fault-block is unusual. Such a block is commonly expected to settle because of the small base in proportion to the weight of the block, while downward-widening blocks are commonly forced upward. In most regions that have been described, downward-narrowing blocks have sunk. It seems reasonable to believe that differential vertical forces that left marine deposits more than two miles above sea-level could have caused a relative upward movement, even for several thousand feet, of a downward-narrowing block while the range was squeezed laterally.

AGE OF FOLDING AND FAULTING

From the structural relations it is evident that the folds and faults are but different expressions of the work done by the orogenic forces which produced that part of the Sawatch Range in the area considered. Faulting probably continued after folding had ceased and possibly to a slight extent after the batholithic intrusion. Whether the folding and faulting were completed in a single period of crustal disturbance or whether they resulted from several of the various post-Paleozoic movements that have been recorded in the rocks of the Rocky Mountains, is indeterminable from observed facts.

There was no pronounced folding within the mapped area, after Tomichi sedimentation began, until after the deposition of all the Paleozoic sediments now seen in the region. This is evidenced by the absence of pronounced angular unconformities. Even if there was any considerable elevation without folding between Ordovician and late Paleozoic times, the region was depressed below water-level during the time of deposition of the youngest consolidated sediments now represented. There is no reason to believe that any part of the general area was greatly elevated prior to the deposition of the Kangaroo formation. The older sediments are mainly off-shore deposits which indicate a considerable removal from land while they were being deposited. Except where they have evidently been removed by erosion the Ordovician and, in some places, later sediments extend from near Poncha Springs about fifteen miles east of Monarch Pass, to the west end of Fossil Ridge about twenty miles west of the Continental Divide. The granite boulders in the Kangaroo formation indicate either proximity to a pre-Cambrian land area or very strong currents. It is not improbable that an adjacent land mass was elevated before the Kangaroo formation was deposited.

Arkose, unlike any local formation older than the Kangaroo, found on the Continental Divide south of Vulcan Mountain, indicates that the present divide at this point was under water while at least part of the Kangaroo beds was being deposited, if not later. Evidence that the submerged portion of the divide was at least several miles long is found about a mile and a half north of Monarch Pass in the limestone and quartzite which remain on the divide, notwithstanding the favorable position for rapid erosion on account of superior elevation and anticlinal structure. The divide has doubtless been exposed to erosion as long as has the ridge west of the Lake fault, from which at least 4,000 feet of sediments and an undetermined amount of granite have been eroded. Figure 3 is a graphic attempt to illustrate conditions at the close of the orogenic disturbance, had it been rapidly completed without allowing time for erosion. The movements very probably extended over a long period of time, and hence erosion may have prevented the represented beds from reaching the height indicated. On the other hand, only the beds now actually represented in the region are considered in the diagram and no account is taken of possible younger deposits. It is probable that the original divide was either at the crest of the anticline in which the valley heading east of Central Mountain has been cut, or was much farther east, passing through or near Missouri Hill. (See fig. 3.)

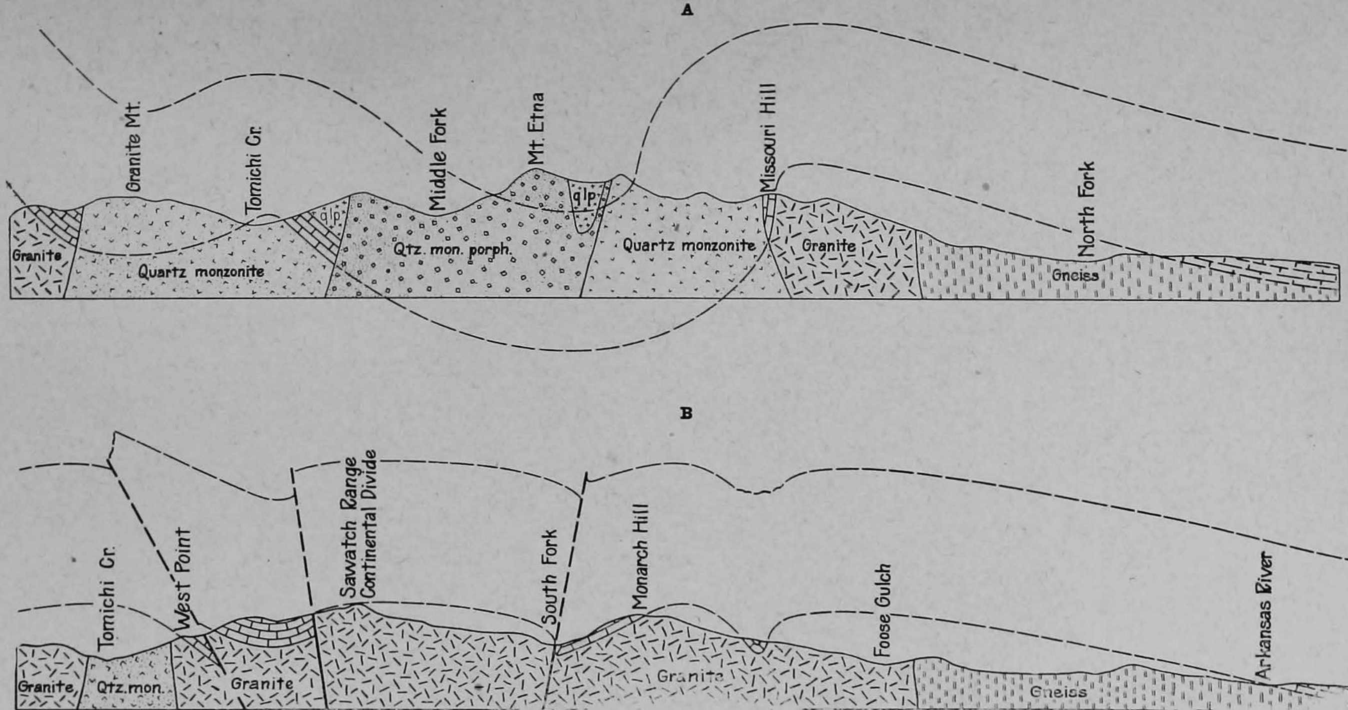


Figure 3.—Probable attitude of Paleozoic strata of Sawatch Range at close of period of deformation, not making allowance for erosion, which probably began before deformation was complete. Continuous lines represent known boundaries; broken lines indicate probable position of former boundaries. The upper broken line indicates the probable upper limit of the known Paleozoic sediments; the lower broken line indicates probable lower limit of the Paleozoic sediments previous to the intrusion of igneous rocks.

A, east-west section through Mount Etna; B, east-west section through Maysville.

THE SAWATCH ISLAND

The late S. F. Emmons,[1] in his monumental work on the Leadville district and in a later paper, gave the name Sawatch Island to the supposed land area which he believed had occupied the position of the present Sawatch Range during the Paleozoic and Mesozoic eras, and the name has since been used by geologists working in central Colorado. Emmons defined the Sawatch Island as an elliptical area whose outlines were approximately those of the Archean area of the Sawatch Range as represented on the Hayden map and whose length was about seventy-five miles and maximum breadth about twenty miles.

This tract includes the Monarch and Tomichi districts, where both early and late Paleozoic sediments are found on and near the crest of the range. In addition to the sedimentary areas shown on the accompanying map, there are several other areas of sedimentary rocks west of the divide as far north as Tincup, which is about fifteen miles north of Whitepine. The beds near Tincup, according to Hill,[2] dip 20° to 70° eastward, toward the older rocks against which they are faulted. The east limb of the syncline whose west limb is represented by these beds was evidently east of the crest of the range. It may have been absorbed by the Princeton batholith. There is another area of eastward-dipping sediments high on the west slope of the Sawatch Range, if not at the crest, not far south of Tincup Pass. Since these beds were seen only from a distance, it is not known whether they are cut off, on the east, by a fault or by the batholith.

The Hayden map, from which Emmons evidently drew largely in forming his opinion of the Sawatch Island, shows neither the sediments mentioned nor the Princeton batholith. It is possible that a detailed study of the range toward the north will show other occurrences of Paleozoic and post-Paleozoic rocks. The reasons which Emmons[3] advanced for the antiquity of the Front Range—namely, the overlaps, or the variable occurrence from place to place of beds of widely different age resting on the pre Cambrian rocks—do not hold for the Sawatch Range. According to the Hayden map the Sawatch Range is fringed by early Pale-

[1] Emmons, S. F., Geology and mining industry of Leadville, Colorado: Mon. U. S. Geol. Survey, vol. 12, 1886; Orographic movements in the Rocky Mountains: Bull. Geol. Society of America, vol. 1, 1890, pp. 245-286.

[2] Hill, J. M., Notes on the economic geology of southeastern Gunnison County, Colorado: Bull. U. S. Geol. Survey No. 380, 1908, pp. 21-47.

[3] Mon. 12, U. S. Geol. Survey, p. 20.

ozoic beds. Hayden[1] believed that "at some period comparatively modern, 10,000 or 15,000 feet of sedimentary beds extended uninterruptedly from the South Park across the interval now occupied by the Sawatch Range."

Whatever may be the age of other parts of the Sawatch Range, the evidence is strong that a section from Monarch Pass northward about twenty miles was not elevated above sea-level until late Paleozoic or post-Paleozoic time.

JOINTING

In general, there is very little regularity in the jointing of the rocks in the area surveyed. However, the quartz latite porphyry, near the north border of the chonolith, shows pronounced columnar jointing. These columns, which are conspicuous at Chalk Creek Pass, stand nearly vertical.

More or less regularity of jointing can be seen locally in almost any of the other varieties of rock, but the regularity covers only a small area. The joint-blocks of nearly all the rocks are small, though in some parts of the Princeton quartz monzonite the blocks are of large dimensions, up to fifteen or twenty feet across.

CAVES AND UNDERGROUND CHANNELS

The formation of caves and development of subterranean drainage are genetically connected with jointing, folding, and faulting which formed fractures and thus facilitated the circulation of ground waters. Limestone is taken into solution and removed by these waters with comparative ease. The caves thus formed are small in this district. The largest noted was cut in the Shamrock mine at the limestone-granite contact and is about six or eight feet wide; the bottom is about fifty feet below the tunnel level; above the tunnel level the cave has not been explored, but the strong air current suggests a vent to the surface about 200 feet above. Another, perhaps somewhat smaller, was found in the same mine. Others may be seen at the creek-level in Garfield.

Just below the stone quarry west of Garfield a large stream issues from beneath the limestone south of the creek. This may or may not have direct connection with the creek higher up. A short distance south of Garfield a stream emerges from beneath a

[1]Hayden, F. V., Ann. report of the U. S. Geol. and Geog. Survey of the Territories, 1876, p. 48.

mass of granite talus, and doubtless has flowed some distance through the limestone. At Monarch a short branch of the creek has its visible source in an excellent spring which furnishes the village with water for domestic use, and could adequately supply a town many times larger. A somewhat smaller stream issues from the limestone half a mile east of Garfield. This is probably the exit of the underground channel which drains the bench-like area three-fourths of a mile south of the spring. This area is nearly flat for a considerable extent, as may be seen from the topographic maps. Morainal material forms a barrier along the north side, except at the northeast corner, where there is a small ravine — presumably an outlet for storm waters only. During the field season no water was running through this outlet although there was an abundance of melting snow above. Another large spring is found in the granite in the valley between Lost Mountain and Missouri Hill. Spring Creek, in the Tomichi district, has its source in a large spring in or near the Morning Glim fault.

Underground streams, perhaps in fault-planes, are indicated in the upper part of Taylor Gulch and below a depression heading toward Taylor Mountain, where there is little or no surface drainage during the season of melting snow.

IGNEOUS INTRUSION

FORMS OF INTRUSIVE BODIES

Classified according to form, the post-Carboniferous intrusive bodies, wholly or partly within the area mapped, are: (1) a batholith, (2) stocks, (3) chonoliths, and (4) dikes and intrusive sheets.

Although there are all gradations in size from a small stock to a large batholith, the contrast in size between the body here called a batholith and those called stocks is so great that few, if any, geologists would be likely to object to the classification used. In order to give definiteness to the terms "stock" and "batholith," Daly[1] proposes that "a body of the kind exposed in an area of less than 200 square kilometers is a stock; a similar body with a larger area is, accordingly, a batholith." In the region under consideration the bodies of this class are exposed over areas which are either much less or much greater than the maximum area proposed for a stock.

[1] Daly, R. A., The classification of igneous intrusive bodies: Jour. of Geology, vol. 13, 1905, pp. 485-508.

THE PRINCETON BATHOLITH

The Princeton batholith is really composite near its south border, being composed of stocks, chonoliths, and dikes, which all form one connected mass with the main batholithic intrusion of the Princeton quartz monzonite. These intrusions differ greatly in form as well as content and there are, moreover, stocks and dikes outside of the main batholith. Hence the units will be treated separately, and in this section only the features of the largest intrusion will be noted.

The northern limits of this quartz monzonite batholith, which lies mostly north of the area mapped, are not known. It probably extends to the southeast slope of Mount Yale about fourteen miles north of Shavano Mountain. Its east border is covered by surficial deposits at the foot of the east slope of Mount Princeton nine miles north of Shavano Mountain. It is exposed continuously from the east slope of Mount Princeton to Tincup Pass on the Continental Divide, about fifteen miles west. Nearly all the Chalk Creek mining district lies within the area through which the batholith is exposed.

One large dike-like apophysis extends southwest into the Monarch district nearly to Boss Lake, while the Tomichi and Quartz Creek districts include a considerable part of the batholith within their boundaries. In areal extent the quartz monzonite which forms this batholith is the most important post-Carboniferous rock in at least four mining districts. It is exposed throughout an area of probably at least 200 square miles.

In the mapped area the walls of this batholith are, in most places, in so far as they can be observed, vertical or inclined at a high angle from the horizontal. The dike-like apophysis in the Monarch district shows evidence of widening downward. In the Condor shaft and tunnel in Hunkydory Gulch the dip of the northwest contact of the quartz monzonite is 70° to 75° northwestward. This is about 1,500 feet lower than the exposure of the same contact between Taylor and Etna mountains, and is probably much farther below the original upper surface of the batholith. On the other hand, the contact between the quartz monzonite and gneiss on the steep slope on the south side of Browns Gulch dips northeastward—that is, away from the gneiss—at an angle of about 85°. It holds this dip quite uniformly, as far as it can be seen, over 1,000 feet vertically. Near Cree Camp and Taylor Mountain the contact at the surface is nearly vertical or perhaps dips slightly away from the older rocks. However, the presence of three small quartz monzonite stocks in this vicinity suggests that the main body of quartz monzonite extends a considerable distance toward the southeast under the sedimentary rocks and granite. Further, several nearly vertical granite dikes in the sedimentary strata on the southeast slope of Taylor Mountain are identical in composition with known granite apophyses from the quartz monzonite near Boss Lake, and very probably extend downward to the southeastward-dipping surface of quartz monzonite. The supposition of a southeast-dipping surface of the quartz monzonite under the sediments is strengthened by the wide contact-metamorphic zone southeast of the main stock, wollastonite having developed in marble and tremolite in limestone nearly two miles away from the surface exposure of the main stock. In the Tomichi district the quartz monzonite batholith appears to have approximately vertical walls, except on Porcupine Ridge, where it is inferred from the relationships of rock on the dumps of caved prospects that quartzite overlies the quartz monzonite. But this is probably a remnant of the roof of the batholith that has not been eroded away, rather than the wall rock. From the facts stated it will be seen that, in so far as has been observed, the Princeton batholith does not, in general, materially widen or narrow with increasing depth.

STOCKS

The granite, quartz monzonite gneiss, quartz diorite, Pomeroy quartz monzonite, and part of the Princeton quartz monzonite and quartz monzonite porphyry occur in stocks.

From the geologic map it will be seen that the stocks show a considerable variety of outline, in plan. The walls, in so far as they can be observed, are vertical or nearly vertical.

The stock of quartz monzonite gneiss, which extends northeast from Mount Etna, probably retains but little of its original outline, having been cut by several later intrusions. In Hunkydory Gulch, where it is separated from the Princeton quartz monzonite by a wide dike of porphyry, the contact probably has nearly the same dip as the wall of the quartz monzonite body, that is, 70° to 75° northwestward, and hence the stock of gneiss grows somewhat narrower with increasing depth. As before stated, the northeast wall of this stock dips northeast about 85°, that is, away from the gneiss. The contact between the gneiss and andesite is nearly vertical, but this is probably not the original wall of the gneiss. The contact of the stock of quartz monzonite gneiss on the east slope of Shavano Mountain is poorly exposed, but, as nearly as can be determined, the northwest and southeast sides of the stock hold a fairly uniform course across ridges and gulches. indicating nearly vertical walls.

The quartz monzonite porphyry stock of Middle Fork widens slightly with increasing depth, where the dip of contact with the surrounding rocks can be observed. West of Camp Summit this contact dips toward the older rocks at an angle of 85°.

At the south and southeast margin of the Pomeroy quartz monzonite the contact dips under younger intrusive rocks at an angle of 25° to 45°, which is probably the dip of the original upper surface of the quartz monzonite.

Excepting the instances mentioned, there is no observed evidence of undoubted stocks in the area mapped having inclined walls.

CHONOLITHS

Daly[1] has proposed this name for "an igneous body injected into dislocated rock of any kind, stratified or not; of shape and relations irregular in the sense that they are not those of a true dike, vein, sheet, laccolith, bysmalith, or neck; and composed of magma either passively squeezed into a subterranean orogenic chamber or actively forcing apart the country rocks." In the Monarch district there is what might be called a composite chonolith, made up mainly of two chonoliths intruded at different times and composed of different kinds of rock.

Andesite chonolith.—The larger, and probably the older, chonolith is composed of andesite and is in the northwest part of the Monarch district. It has an average width at the surface of more than a mile and a length of a little more than four miles. On the northwest side the lower surface dips southeastward 40° to 45°. This high inclination from the vertical results in a bending of the surface boundary toward the southeast where the andesite and underlying Pomeroy quartz monzonite have been cut away by erosion in the gulches, as seen on the geologic map. The southeast wall of the chonolith is nearly vertical, and hence the andesite mass narrows downward. A cross-section of this body, based on field observations and data taken from the map, is shown in EE on Plate III. The section as constructed cannot

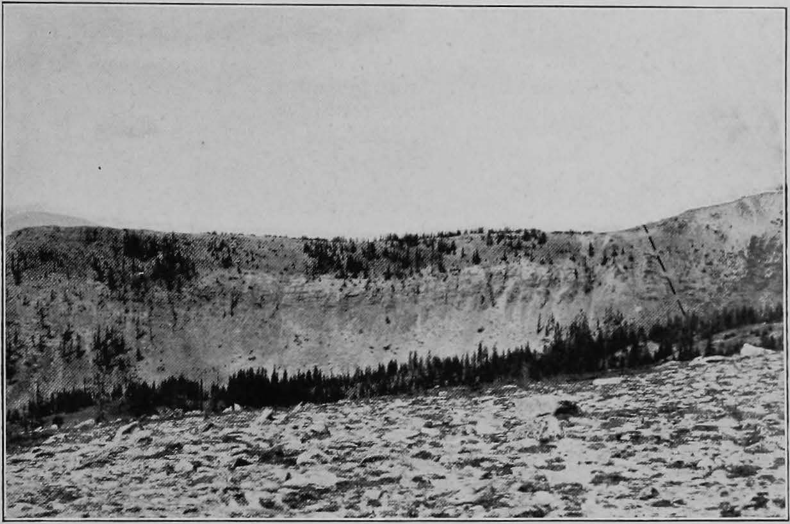
[1] Jour. of Geology, vol. 13, 1905, p. 499.

be far from correct to a depth of at least 1,500 feet. Below that level the diagram is hypothetical.

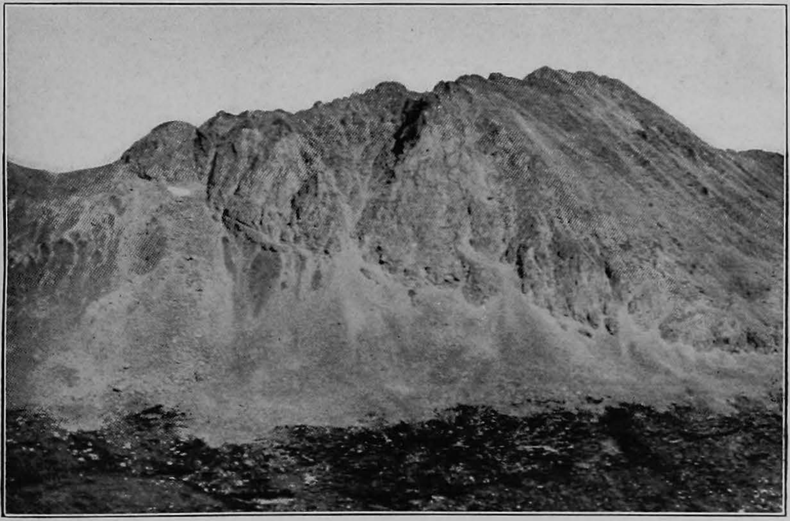
The microcrystalline character of the groundmass of the andesite suggests that the magma cooled fairly rapidly at the surface or under a comparatively thin cover. If it had reached the surface as an extrusive rock, the walls of the channel through which it would pass would probably have become sufficiently heated to prevent rapid cooling of the mass remaining in the channel. The slower cooling would hence result in a probably higher degree of granularity than the rock shows. To conclude that the andesite now exposed represents a thick flow it would be necessary to suppose that it was extruded into a trough one of whose walls was vertical and at least 1,500 feet high, making no allowance for subsequent erosion. Although no trace of the former cover remains on the highest exposures of andesite, remnants of what may have been the roof of the chonolith are to be seen in the large masses of Paleozoic sediments high up on the south slope of Calico Mountain.

Quartz latite porphyry chonolith.—A second large body which appears to have been injected, is seen in the quartz latite porphyry of Middle Fork. The east and south boundaries of the original mass have been disturbed by later intrusions and eruptions to such an extent as to prevent the determination of the original shape of the body on the sides named. But on the north and northwest the latite porphyry mass overlies the older rock with a gently dipping contact. On the steep north slope, about half a mile east of Chalk Creek Pass, the dip of this contact is about 25°. Plate XIII shows the contact between the quartz monzonite porphyry and overlying rock just south of Pomeroy Pass. Almost an exact counterpart of this is shown on the southwest slope of Chapman Mountain a mile west of Pomeroy Pass. At Pomeroy Pass the quartz latite porphyry is separated from the Pomeroy quartz monzonite by about 200 feet of dacitic porphyry, which was evidently intruded in dike-like form between the quartz monzonite and overlying rock prior to the intrusion of the quartz latite porphyry.

The reasons for inferring that the quartz latite porphyry is an intrusive rather than an extrusive rock are similar to those mentioned in connection with the andesite. The incomplete crystallization of the groundmass indicates comparatively rapid cooling, while the relation of this rock to the surrounding rocks



A.—MORNING GLIM FAULT NEAR HEAD OF NO NAME CREEK
Sediments abut against granite at plane indicated by dashes.



B.—CONTACT BETWEEN POMEROY QUARTZ MONZONITE STOCK AND OVERLYING CHONOLITH AT POMEROY PASS

practically precludes its being a thick flow. In this case the contact with the older rocks, which is well exposed near Pomeroy Pass, shows no evidence of an extrusion over a surface of erosion.

DIKES AND SHEETS

In the chapter on petrography mention is made of the various rocks which occur in dikes most of which are less than fifty feet wide. Special mention need be made here of only one dike—that which extends from Browns Gulch to the west slope of Clover Mountain, a distance of eight and a half miles. In the vicinity of Middle Fork and Monumental Mountain the dike widens to form a large stock; or the extensions of the dike toward the northeast and the southwest of the stock of Middle Fork might be considered great apophyses from the stock. There is little, if any, doubt that the stock and dike were formed at the same time and by the same magma. This dike varies in width from several hundred feet east of Jennings Gulch to fourteen feet south of Shavano on North Fork.

Intrusive sheets—that is, masses of dike-like form intruded parallel to the bedding of stratified rocks—are relatively unimportant in the area mapped. They are found, however, in both districts surveyed, and are generally formed of porphyry. They are commonly continuous with dikes—that is, extensions of dikes—which may cut the strata at any angle.

RELATION OF INTRUSIONS TO PREVIOUS STRUCTURE

It is not improbable that the intrusion of such large masses may have had some influence on the previously existing structure of the region, but no important effects of intrusion other than contact metamorphism have been observed in the older rocks. Not even an appreciable gneissoid or schistose structure has been developed in the older rocks near the intrusions, and no local folding has been seen. Eruptive contacts are found cutting at almost any angle beds, folds, and faults, as well as planes of schistosity. The observed phenomena, therefore, indicate that the intrusion was effected after the crustal deformation; the latter may have been an important contributing cause of the intrusion.

Obviously the study of a small area bordering a large batholith does not justify any conclusion as to the relation of the batholith and its satellites to the broader pre-intrusion structure.

Only after the entire region invaded by the batholith has been studied and the general facts of crustal folding determined, can a discussion of the subject have any considerable value. In any event, such a discussion must necessarily be more or less speculative.

CONTACT METAMORPHISM

The endomorphic contact metamorphism of the intrusive bodies of this region was unimportant. In a few cases a finer grain or greater acidity than the average of the intrusion may be seen near the margin. The exomorphic contact-metamorphic effects on intruded igneous rocks are relatively unimportant. These appear to be local and confined to a narrow strip near the intrusive body. They include a directional structure caused by shearing, an insignificant crushing and grinding, and mineralization of the intruded rocks.

On the other hand, every variety of the Paleozoic sediments of both districts surveyed has undergone pronounced metamorphism. This was doubtless effected mainly by the intrusion of the Princeton quartz monzonite, but there are evidences that other intrusions—even the dikes—played a part locally. The contact-metamorphic zone in the sedimentary rocks will average more than a mile in width from the border of the exposed quartz monzonite, and there has locally been slight development of contact-metamorphic minerals at least two miles from the outcrop of the intrusive rock. It is probable, however, that in some places the quartz monzonite extends under the sediments and is less remote vertically from the sedimentary outcrops than it is horizontally.

The extreme metamorphism of the sediments west of the Star fault in contrast with only incipient metamorphism of the same strata east of that fault virtually proves that the pronounced faulting was consummated prior to the intrusion of the quartz monzonite. Had faulting succeeded the intrusion and attendant contact metamorphism an equal degree of alteration might be expected in the same strata on both sides of the fault.

Given a few weeks in the Monarch and Tomichi districts for the field study of contact metamorphism and sufficient opportunity later for microscopic and chemical analyses, one could doubtless collect evidence that would contribute a little toward the solution of contact-metamorphic problems. In the course of the present survey no time was available for the special study of the subject, and the only information at hand is that which was gained incidentally during the areal mapping and by a subsequent examination of the specimens collected. Consequently this section will be chiefly descriptive.

MARBLE

Marble occurs in both the Monarch and Tomichi districts in great masses, and is perhaps the commonest contact-metamorphic rock in the region. Large exposures are found on Missouri Hill, in Taylor Gulch, about a quarter of a mile west of Monarch, on Lake Hill, West Point, Porcupine Ridge, and Mount Stella, and near the northwest corner of the Tomichi district.

The texture ranges from very coarse to fine-granular. Although the purer marble is commonly white, a blue variety is not rare. Good examples of medium-grained, blue marble may be seen in the quarries at Garfield and in the Jewell tunnel. On the divide near the head of Taylor Gulch a coarse blue marble contains grains up to half an inch in diameter. In the last named locality the coarest white marble is also found.

The microscope shows the purest marble to be composed entirely of calcite or dolomite grains, practically all of which are polysynthetically twinned. But in many places, silicates have been developed in the marble in the process of metamorphism; less commonly, graphite has been formed. Varieties containing the minerals named will be briefly described in the following paragraphs.

Wollastonitic marble.—Although in the main the marble of the Garfield quarry is composed of nearly pure calcite, there are occasional bunches of white wollastonite having a maximum diameter of about one inch. The wollastonite contains sufficient intermixed calcite to cause effervescence in acid. The hardness of the wollastonite is about 3, owing probably to alteration and the presence of considerable calcite. The mineral has a radiating structure and good cleavage. In thin section it is seen to be fibrous.

Graphitic marble.—Black marble which closely resembles carbonaceous shale in appearance, is found in a few places in the Monarch district. It is possible, also, that many beds which were considered to be shale when observed in the field may contain a high content of lime. The black marble is fine to medium in texture. A thin section of very fine-grained black marble from the south slope of Syncline Hill contains about 80 to 90 per cent of calcite, in small untwinned grains. Fine grains of graphite and magnetite are inclosed by the calcite and are abundant in the interstices among the calcite grains. A thin section of a medium-grained black marble from north of Boss Lake contains about 90 to 95 per cent of calcite. The remainder is chiefly graphite and magnetite. In this specimen a small proportion of the calcite grains are twinned.

Olivinitic marble.—The marble inclusion in the quartz monzonite on Mount Stella varies considerably in composition. A specimen taken from near the northwest corner contains numerous dark spots, and somewhat resembles a fine-grained diorite in appearance. The microscope discloses magnetite powder, a colorless, isotropic mineral, grains of olivine, and much calcite. The colorless, isotropic mineral is in minute grains with a high index of refraction and a border of magnetite powder. It is probably a garnet. The olivine is abundant in small crystals with rude outline. Many individuals examined in convergent light are optically negative, indicating a considerable percentage of iron. The olivine shows the ordinary serpentinization. Not far from the olivinitic marble is much massive serpentine in veins and patches one to two inches thick inclosed by coarse calcite. This serpentine is probably derived from the olivine

A specimen of white marble with a few grains of olivine and no garnet was taken from a prospect on the northwest slope of Vulcan Mountain. A specimen from a prospect tunnel near the Morning Star mine is a fine-grained, bluish gray marble speckled with small dark green crystals and a few pyrite grains. In thin section the rock is seen to be made up in large part of small calcite grains, of which comparatively few are twinned. Very little pyrite is present. A mineral of the olivine group in fairly well shaped crystals forms perhaps 10 per cent of the rock.

Diopsidic marble.—On Missouri Hill the white marble derived from the Ordovicion limestone contains many nodules and seams which replace chert nodules and seams of the original sediments. The white cores of the nodules and main part of the seams are composed of microgranular diopside. The green borders are of serpentine—mainly massive, in small part fibrous—derived from the diopside. In thin section the diopside is seen to be mostly in very fine grains with a few aggregates of coarser grains. Most cross-sections of the diopside show clinopinacoidal cleavage. A few individuals have prismatic cleavage in addition. A few small grains of diopside are found in the surrounding marble which is composed mainly of twinned calcite grains. The diopside is clearly a replacement of the original chert of the limestone. Apparently under the influence of the metamorphic agencies originating in the intrusion of quartz monzonite, the calcium-magnesium carbonate of the limestone reacted with the silica of the chert, which process resulted in the formation of diopside.

Near a dike in Cree Camp the marble carries more coarsely crystallized diopside associated with asbestos. The silicates here are in bunches of radiating prisms and fibers which do not preserve any original structure of the sediments.

Ophicalcite.—In the paragraph on diopsidic marble mention was made of the common serpentinization of the diopside. A variety of serpentinous marble different from that described was found in Taylor Gulch, in the Jewell tunnel. This is a dark greenish-gray, dense rock having numerous dark-colored, phenocryst-like forms two to four millimeters long. The microscope shows these forms to be serpentine. The bulk of the rock is made up chiefly of minute, untwinned grains of calcite. It is probable that both serpentine and calcite were derived from a lime-magnesia silicate and hence formed subsequently to the contact metamorphism of the original sediments.

DIOPSIDE

In addition to its being a minor constituent of marble and of the matrix of some quartzite, diopside locally occurs in masses several feet thick and many yards long. A few hundred feet west of the Victor mine a prospect discloses one of these bodies which replaces a stratum of the original sediments at least six feet thick. Smaller patches of the same mineral are found in the limestone a few feet east. On the north slope of West Point, blocks on the dumps of prospects at the base of the Tomichi limestone show that a mass of diopside several feet thick exists here.

The diopside is massive and, on fresh surfaces, is pale greenish-gray. Much of it is free from any admixture of other minerals. Calcite may occur in small patches and also in very thin seams which fill fracture planes. In thin section the diopside is seen to be micro-granular; a few grains show prismatic cleavage. Most of the diopside is practically unaltered, but a slight degree of serpentinization has taken place along the border of individual grains. Serpentine, in bands up to two inches thick, occurs near one border of the mass west of the Victor mine. The diopside here is slightly brecciated, and in openings are seen many tufts of small acicular crystals of aragonite, associated with serpentine. Evidently both aragonite and serpentine were derived through the alteration of diopside. A specimen of galena in contact with diopside was found on the dump.

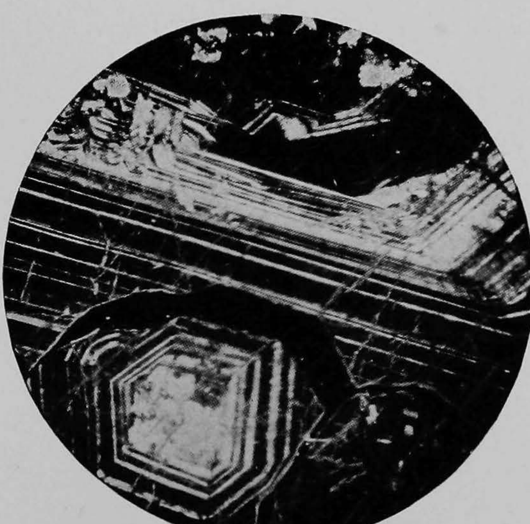
On the north slope of West Point much of the diopside is associated with an equal quantity of a colorless to pale green micaceous mineral with hexagonal outline. The crystals of the micaceous mineral are mostly less than two millimeters in diameter, and commonly inclose minute grains of diopside. In thin section the mica is colorless and does not sensibly absorb light vibrating in any plane. It gives a perfect uniaxial interference figure and is optically negative. As determined by comparison with diopside the birefringence reaches at least .04. Blowpipe and chemical tests show that the mica is phlogopite.

GARNET (ANDRADITE AND ALMANDITE)

Garnet is very common near the head of Taylor Gulch and at Cree Camp in the contact-metamorphic zone. It ranges from a minor constituent in the lime-silicate metamorphic rocks to practically pure garnet rock. In texture it varies from massive to coarse-granular, forming crystals nearly an inch in diameter. The color is commonly gray-green, yellow-green, or brown. In a few exposures the weathered surface is black, owing probably to a coating of maganese dioxide.

Fine-granular, massive, gray-green to black garnet replaces sediments through a thickness of about 35 feet, on the east shoulder of Taylor Mountain, just above the Ouray limestone. West of this, for many yards, narrow bands of garnet, in part coarsely crystallized, alternate with beds of quartzite and baked shale. Fine-granular garnet is also found in considerable quantity near the base of the Ordovician limestone along the trail which goes down into Cree Camp from the divide at the head

A.—GARNET SHOWING ANOMALOUS DOUBLE REFRACTION IN SECTORS
Crossed nicols; x 16.



B.—GARNET SHOWING ANOMALOUS DOUBLE REFRACTION IN ZONES
Crossed nicols; x 14.

of Taylor Gulch. Smaller quantities occur in the marble near Cree Camp, along the granite-limestone contact on the southwest slope of Missouri Hill, and on the west side of Taylor Gulch near the quartz monzonite. In the New York mine garnet was found associated with zinc blende and diopside. The best ore of the Clinton mine is said to have been associated with garnet.

Outside of the localities mentioned not much garnet was observed. However, not far east of the highest workings of the Columbus mine, in Columbus Gulch, coarsely crystallized garnet may be seen on a prospect dump. Part of the marble on Mount Stella carries an isotropic mineral which is probably garnet. Near the northwest corner of the Tomichi district, a loose block of hornfels coated on one face with numerous small red garnet crystals, was found.

Many specimens from Taylor Gulch and Cree Camp were tested qualitatively and found to be andradite, $3CaO.Fe_2O_3.3SiO_2$. A small quantity of aluminum commonly replaces part of the iron. The red garnet from the Tomichi district is shown by chemical tests to be almandite, $3FeO.Al_2O_3.3SiO_2$. Rhombic dodecahedrons are present on all the well developed crystals observed. Many andradite crystals show a combination of the dodecahedron and trapezohedron.

Thin sections of andradite show two types of anomalous double refraction. In the first the entire crystal is doubly refracting, in four, five, or six sectors (Pl. XIV, *A*). The second type contains alternating isotropic and anisotropic zones (Pl. XIV, *B*). The core of a few crystals is anisotropic while the outer part is in zones. The core of other crystals is isotropic, while the outer part is zoned.

Epidote and calcite, in small amount, are commonly associated with the garnet. Quartz as an associate is perhaps less common.

EPIDOTE ROCK

Epidote, resulting from the metamorphism of calcareous sediments, is one of the commonest contact metamorphic minerals in the region mapped. In only a few places, however, does it form the bulk of the rock. Rock having a high epidote content occurs in considerable quantity on the west slope of Missouri Hill in the sedimentary area not far from the quartz monzonite. Large bodies of similar rock are inclosed by the quartz monzonite on the northeast shoulder of Taylor Mountain. These evidently represent masses of the sediments picked up by the monzonite and completely altered.

Probably 80 to 90 per cent of the rock mass is composed of yellowish-green epidote. Freshly broken pieces show small cavities into which numerous crystals of epidote project. Chemical tests show the presence of considerable manganese in the epidote. In thin sections a small quantity of chlorite and some quartz are seen in addition to the epidote which is strongly pleochroic in yellow and green tones. The epidote is automorphic toward the quartz which poikilitically incloses many small epidote crystals.

ANTHOPHYLLITE-EPIDOTE ROCK

This rock is found west of the small quartz monzonite stock west of Cree Camp. It is very tough and on fresh fractures is olive green. Weathered surfaces have a black, sooty coating of manganese dioxide derived probably through the weathering of epidote. In addition to the small grains of yellowish-green epidote, a few grains of quartz and many cleavage faces of a green, finely-fibrous mineral are present. Most of the cleavage faces of this mineral, which the microscope shows to be anthophyllite, are less than three millimeters in diameter.

Under the microscope are seen epidote, anthophyllite, quartz and a litle calcite. The epidote, which is strongly pleochroic, is present in comparatively small amount. It is partly in small, formless grains and partly in well-shaped crystals inclosed by quartz. Quartz and anthophyllite, which make up the greater part of the rock, are present in nearly equal quantities. The anthophyllite is elongated in the direction of the prismatic cleavage traces, but has a rather poor outline with ragged borders. The parallel extinction, positive elongation, perfect cleavage, low relief and birefringence of about 0.025 as shown by the greenish-blue interference color in a section a little less than 0.03 mm. thick are properties which serve to determine this mineral with a good degree of certainty. It is light green and perceptibly pleochroic. Z = pale green, Y = yellow-green, X = yellow-green.

METAMORPHOSED SHALE

The shale of the contact-metamorphic zone shows almost every degree of alteration between incipient metamorphism and thorough baking with consequent crystallization. Locally iron sulphides were deposited in small quantity, but it is not possible in every case to determine whether this was effected by chemical combination and crystallization of contained elements or by replacement.

In the less pronounced metamorphism, the shale is moderately indurated and contains disseminated grains or small aggregates of marcasite or pyrite. On the east shoulder of Taylor Mountain the shale near the top of the Ouray limestone, carries small grains of iron disulphide and many minute spherical black patches which evidently contain a large proportion of graphite. West of Taylor Gulch a hard, dense, light gray to dark gray hornfels is abundant. The hornfels on the southwest slope of Calico Mountain in contact with the quartz monzonite gneiss contains a little graphite and numerous minute grains of monoclinic pyroxene. Near Boss Lake pyrrhotite, apparently as a replacement, occurs in small patches and narrow bands in a hard, black shale.

Cordierite hornfels.—Cordierite hornfels, which has been formed by the alteration of shale, is one of the most common contact-metamorphic rocks of the Monarch district, and will be described in considerable detail. It is especially abundant on the south slope of Syncline Hill, about half a mile east of the small quartz diorite stock and a mile south of the exposure of the large body of quartz monzonite. Several of the shale beds east of Kangaroo Gulch have been changed to cordierite hornfels. This rock is also found near the porphyry dike about a mile east of Boss Lake.

The cordierite hornfels is a very hard, dense, dark gray rock which has lost its original bedded structure. It often has a bluish or pink cast. Weathered surfaces are dirty gray. Surfaces but little weathered show numerous, minute gray or white specks about half a millimeter in diameter; these are altered surfaces of cordierite grains which locally make up nearly one-third of the rock. On fresh fractures these grains can scarcely be detected. Surfaces long exposed to weathering are pitted owing to the complete removal of the cordierite. The rock gives a metallic clink when struck with a hammer, and breaks with an uneven fracture, into sharply angular fragments.

Thin sections from several localities were examined, but one from a specimen taken from three feet below the porphyry dike about a mile east of Boss Lake shows the greatest development of cordierite. Under the microscope the rock strongly resembles a porphyry in texture. Cross-sections of the cordierite crystals are roughly hexagonal to circular in outline and nearly all show the characteristic twinning. This produces six sectors which extinguish in pairs of diagonally opposite sectors (Fig. 4). The cordierite crystals are crowded with microscopic inclusions among which are numerous minute flakes of biotite, a few crystals of apatite, and occasional black grains of what is probably graphite.

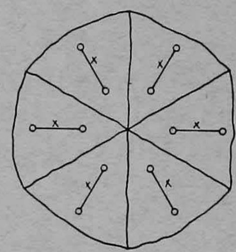


Figure 4.—Diagram of basal section of cordierite in cordierite hornfels.

The microcrystalline matrix forms about two-thirds of the rock mass. Of this about one-third to one-half is biotite in minute brown, pleochroic flakes. The remainder appears to be largely cordierite with a few minute crystals of apatite and some graphite powder.

In a variation from this type the cordierite is in micropoikilitic patches with indistinct outline and no evident twinning. The inclusions in the cordierite and the minerals making up the bulk of the rock are quartz and biotite. The quartz grains here are probably the original sand grains of a shaly sandstone or sandy shale. Another variation shows smaller cordierite crystals, with no pronounced twinning, in an extremely fine-textured matrix.

QUARTZITE

The original sandstones and arkoses of the Garfield and Kangaroo formations have been generally changed to quartzite —probably without the recrystallization of the quartz and feldspar, but by a thorough crystallization of the cementing material. In the specimens that have been examined microscopically, tremolite, diopside, biotite, and magnetite have been formed in varying but considerable quantities. On the east shoulder of Taylor Mountain, the weathered quartzite strikingly resembles an ancient gneiss in appearance. Careful examination shows that the banding is parallel to the original bedding planes. Biotite and magnetite are the chief black minerals of the dark bands.

MISCELLANEOUS CONTACT-METAMORPHIC MINERALS

A few constituents of the contact-metamorphic rocks just described and a few other minerals that have been formed through contact-metamorphic agencies in minor occurrences which cannot be considered rock masses, will be mentioned.

Tremolite.—As noted above, this mineral is a component of certain quartzites. It has not been certainly identified in the marble, though its presence there might be expected. What is very probably tremolite is found in the upper part of the Tomichi limestone along the creek east of Garfield, and in the Ouray limestone near the David H. mine in the Tomichi district. Fine-grained tremolite, in considerable quantity, is associated with serpentine and magnetite in the ores of the Iron King mine in the Tomichi district.

Actinolite.—Actinolite in radiating tufts is associated with magnetite at the limestone-granite contact on the southwest slope of Missouri Hill. A large specimen of dark green quartz associated with garnet crystals, epidote, and actinolite was found in the moraine at Cree Camp. Thin sections show that the green color of the quartz is due largely to inclosed green actinolite. The actinolite is abundant as short, stout crystals which fray out at the ends into multitudes of fibers. The quartz also incloses a great number of very slender, acicular crystals of actinolite which are not connected with the larger crystals. Inclusions of garnet and epidote are also present in the quartz.

Asbestos.—Small patches of asbestos with parallel, or nearly parallel fibers are rarely seen in the marble. In the form of mountain leather the same mineral has been found in small sheets in the marble of Taylor Gulch.

Serpentine.—The occurrence of serpentine in the marble of the Monarch district, and with tremolite and magnetite in the Tomichi district, has been mentioned. In the latter occurrence it may be seen in masses several inches across. On the south slope of Mount Etna it is associated with magnetite and what is probably olivine. But little of the last named mineral is now present. It is probable that all the serpentine noted in these districts has been derived from silicates of calcium, magnesium, and iron that were formed through contact-metamorphic agencies.

Quartz.—Quartz has not been detected in thin sections of the marble, but it is a common constituent of other rocks. It evidently crystallized subsequently to the garnet, epidote, and actinolite. The source of the late-deposited quartz in the contact-metamorphic zone was probably the same as the source of the quartz of the fissure veins in the quartz monzonite.

Metallic minerals.—Magnetite is a rather common mineral in the contact-metamorphic zone. It occurs in bodies from several feet to many yards across, on the southwest slope of Missouri Hill, near the head of Taylor Gulch, on the southeast slope of Taylor Mountain, at Boss Lake, in and near the Morning Glim fault, and on Mount Stella. On the south slope of Mount Etna it is common in curved or distorted bands alternating with serpentine. Sphalerite is associated with diopside and garnet in Taylor Gulch, in the New York mine. Galena was found in contact with diopside on West Point. Pyrrhotite, pyrite, and probably marcasite are found in the shale near Boss Lake.

Though sphalerite, galena, and magnetite are associated with characteristic contact-metamorphic minerals and may therefore be considered of the same origin, there is evidence that part of the magnetite was deposited subsequently to the tremolite and the sphalerite subsequently to the diopside. Microscopic fissures with ragged walls—and hence formed by contraction rather than shearing—are found in the tremolite. Both magnetite and serpentine were deposited subsequently to the fissuring. In a thin section of sphalerite and diopside (Pl. XX, *A*), the sphalerite appears to have replaced some material, probably calcite, after the diopside had formed. The diopside is automorphic toward the sphalerite which incloses small crystals of the former mineral.

CHAPTER VII

LOCAL GEOLOGY

A summary of the geology of individual areas will be given in this chapter for the convenience of those who may want the essential features of a particular area and lack the time to extract them from the details given in previous and succeeding chapters.

MONARCH DISTRICT

MONARCH HILL

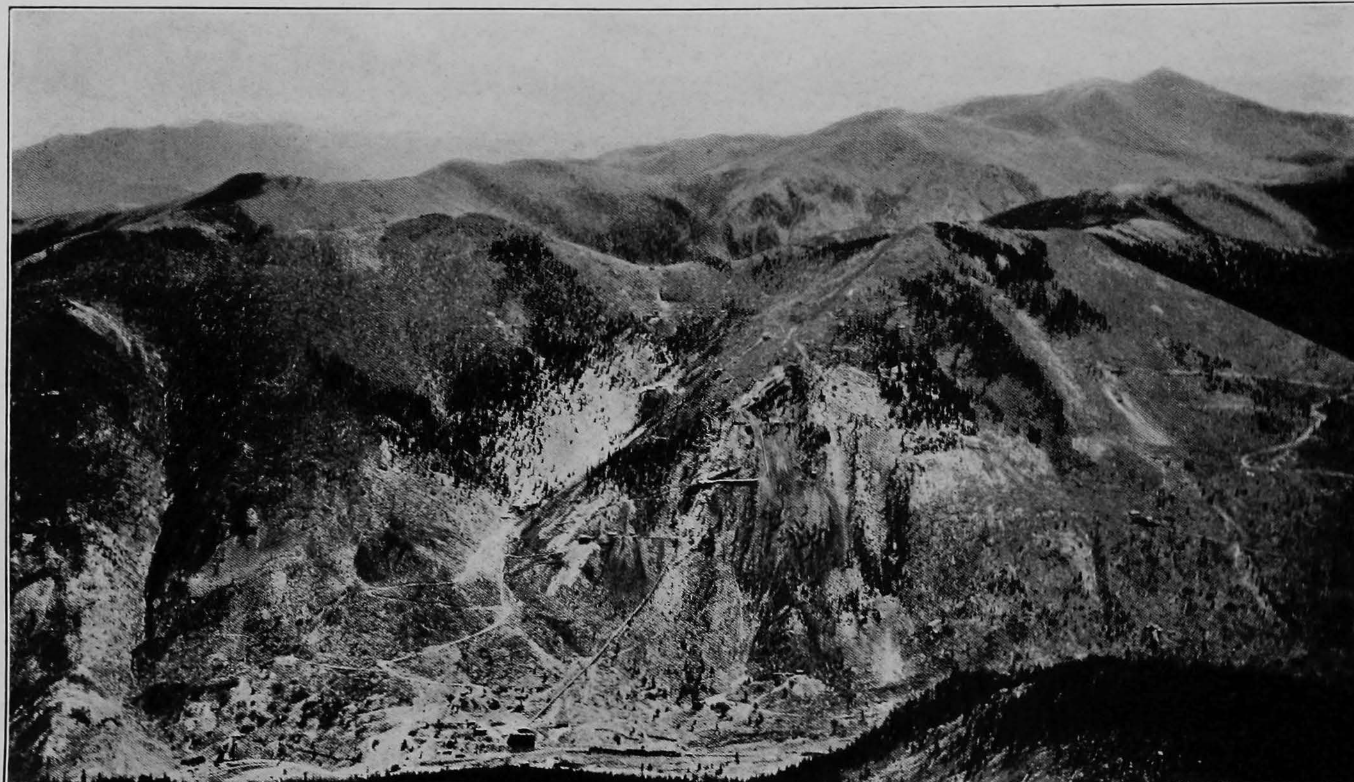
Monarch Hill, as here taken, is the northeast part of a long ridge which extends southwest to the Continental Divide. Pre-Cambrian granite is exposed continuously on the east and southeast slope of the hill from near the crest downward. The same rock forms the entire ridge south of an east-west line about a mile and a half south of Monarch. One narrow dike of porphyry cuts the granite on the east slope about a mile from the highest point. Paleozoic limestone with a little quartzite is exposed on the northwest slope of the hill.

The granite is a gray to reddish rock composed essentially of potash feldspar, quartz, and biotite. It varies from even-granular to porphyritic, and is commonly massive.

Beside occasional small remnants of the Sawatch quartzite lying on the granite, the sediments include the Tomichi limestone, Ouray limestone, and a small part of the Garfield formation. The Tomichi formation, which is of Ordovician age, is composed chiefly of bluish-gray, cherty limestone. The formation is 350 to 400 feet in thickness. At about two-thirds of the way between the base and the top is a stratum, or several strata, of medium to coarse quartzite, locally called the "parting quartzite." The thickness of the quartzite varies from about 20 to 35 feet. The topmost part of the Tomichi limestone is variably dolomitic, shaly, and siliceous in composition. In part it is dark in color and weathers to chocolate brown. Overlying the Tomichi limestone is the Ouray formation which includes strata of both the Devonian and Lower Carboniferous systems. The entire formation is about 600 to 700 feet thick on Monarch Hill. The lower part is a massive gray to blue limestone, part of which is yellow on weathered surfaces. The upper part is black to gray massive dolomite. A few hundred feet south of Monarch is an outcrop of quartzite and conglomerate of the Garfield formation which overlies the Ouray limestone. The quartzite and conglomerate are probably of Upper Carboniferous age.

By strong compressive forces the sedimentary rocks were folded and now form a syncline whose axis trends a few degrees east of north. The strata of the east limb of the fold dip northwest at an average angle of about 35°. The west limb is in part nearly vertical, and in part dips westward at an angle of 25° to 50°, having been overturned by the thrust. Where this limb is overturned the granite is thrust up over the limestone. This overturn evidently passes, near the foot of the hill, into a thrust fault, which trends northward and passes under Boss Lake.

In addition to the fault mentioned—the Lake fault—there are on Monarch Hill at least three faults which strike northwestward. Two of these, the Madonna and the Mayflower, are shown on the geologic map. Because of lack of proof of continuity of the third important fault it is not represented on the map, but it is probably not far from the section which passes through the Hawkeye and Silent Friend mines and was taken along the line D-D of the geologic map. The throw on these three faults is comparatively small. The Madonna fault is a thrust and dips steeply toward the southwest. On the top of the hill the offset of the granite-limestone contact at this fault is about 500 feet. The same contact is offset about 200 feet on No. 6 level of the Madonna mine not far above the creek. The Mayflower fault dips steeply southwest. At the top of the hill this fault is a gravity fault—that is, the downthrow is on the hanging-wall side. It is not improbable that the upthrow is on the same side near the creek level, and the fault therefore a rotary fault. The Hawkeye fault shows a displacement of only a few feet in the Hawkeye mine, but there is strong evidence that the same fault passes through the Silent Friend mine with a much greater displacement.



MONARCH HILL FROM BANANA MOUNTAIN

Ore bodies were deposited in the faults named and spread laterally, replacing much of the limestone walls. The largest known ore bodies are in the form of long shoots and are not far above the granite. (See fig. 10, p. 226.) Other ore shoots in the limestone near the granite have the same trend as the longest known shoots, but it is not known that they were deposited along faults. Still other ore bodies are found in the limestone several hundred feet above the granite.

The South Fork of the South Arkansas has eroded a valley 1,400 to 1,600 feet deep in granite and shale north and west of Monarch Hill. This erosion was effected almost entirely in pre-Pleistocene time before glaciers deposited the moraines which now, with recent alluvium, occupy part of the valley bottom.

SYNCLINE HILL AND BOSS LAKE

The greater part of Syncline Hill is formed of Upper Carboniferous, or Pennsylvanian sediments. The rock of a small area at the top may be of Permian age. The strata are folded into a sharp syncline (Pl. XII) and, on the west, are in fault contact with pre-Cambrian granite. The thrust which brought the granite up into contact with the sedimentary rocks shows a displacement of more than 4,000 feet.

The west limb of the syncline is vertical; the east limb, which is a stratigraphically higher part of the east limb of the syncline on Monarch Hill, has a northwest dip of 30° to 75°. The sedimentary rocks were originally limestone, shale, sandstone, and arkose, but by contact metamorphism they have been largely changed to marble, hornfels, and quartzite. The metamorphism was doubtless brought about by the large intrusion of quartz monzonite whose southernmost exposure is about a mile north of the hill. One narrow dike of porphyry is found on the southeast slope of the hill. Moraines cover much of the east and north slopes.

Boss Lake occupies a depression over the Lake fault at the contact between the metamorphosed sediments and pre-Cambrian granite. The basin was formed by the scouring by a glacier which moved eastward down the valley of Lake Fork. A few dikes of porphyry east and north of the lake and a few dikes of granite north of the lake cut the metamorphosed sediments. Metallic minerals in considerable quantity occur in the metamorphosed sediments and in or near the fault plane. The minerals include pyrite, pyrrhotite, galena, zinc blende, magnetite, and limonite. Gold and silver are present in small amount.

TAYLOR GULCH

Taylor Gulch is a steep valley 500 to 1,000 feet deep, which has been formed by the erosion of Paleozoic sediments, chiefly. The deepest part of the valley is in the Ouray limestone. Outcropping in the valley, from east to west, are the pre-Cambrian granite, Tomichi limestone, Ouray limestone, and Garfield formation. A remnant of the Sawatch quartzite is found in the Lilly mine. All the strata stand nearly vertical. East of the gulch the dip is from 75° west to 70° east. West of the gulch the dip ranges from 55° westward to vertical.

The Paleozoic sediments, for the most part, belong to the east limb of a large syncline into which the syncline of Monarch Hill merges. The granite-limestone contact on the east border of the fold is nearly vertical, and for a considerable distance dips at a high angle toward the east. There has been much faulting near the head of Taylor Gulch, but the faults can be traced only short distances. Similarity of rock on both sides of the dislocations and the covering of talus make it difficult to trace known faults and to prove the existence of probable faults.

The quartz monzonite intrusion which extends southwest nearly to Boss Lake cuts off the strata west of the head of Taylor Gulch. Porphyry dikes are found in the pre-Cambrian granite, Paleozoic sediments, and quartz monzonite. A few granite dikes—apophyses of the quartz monzonite body—cut through the sedimentary rocks. Nearly all the sediments of the gulch have been greatly metamorphosed as a result of the intrusion of quartz monzonite. Marble, quartzite, hornfels, garnet, and epidote are found in abundance.

Several large ore shoots and many smaller bodies in the sedimentary rocks of Taylor Gulch, have been developed. The largest ore bodies hitherto discovered were found in the limestone near the granite, but good ore has been found about half a mile from the granite—that is, nearly half a mile stratigraphically above the oldest sedimentary beds.

There is no known evidence that a glacier occupied the upper part of Taylor Gulch. There are, however, at the lower part of the gulch, remnants of moraines that were probably deposited by the large glacier that moved down the South Arkansas.

CREE CAMP

The oldest strata of Taylor Gulch continue northward to Cree Camp where they are sharply bent, forming an anticlinal fold. The folding, though more gentle, continues for some distance toward the southeast, and at about one-fourth of a mile southeast of the camp the trend of the limestone-granite contact is nearly due south. At less than half a mile from the camp the same contact bends sharply to the east and north, forming a synclinal fold, and continues northward with the same trend that it has in Taylor Gulch, having been offset about two-fifths of a mile. The dip ranges from about 50° to 90°.

The Paleozoic sediments are exposed throughout an area of not more than one-half square mile. On the northwest they are cut off by the quartz monzonite, which is also found in two small stocks surrounded by sedimentary rocks. A porphyry dike trending northeastward outcrops near the camp and again on the southwest slope of Missouri Hill. Nearly all the Paleozoic sediments have been thoroughly metamorphosed. Marble, quartzite, garnet, and epidote are abundant. Two mines in the limestone have produced ore.

A moraine several miles long occupies the valley below the camp.

MIDDLE FORK

The deep valley of Middle Fork, which is nearly five miles long, has been eroded chiefly in Paleozoic sediments, quartz monzonite, quartz monzonite porphyry, and quartz latite porphyry. It is separated from the valley of Chalk Creek by Chalk Creek Pass which, though over 1,200 feet in elevation, is about 1,000 feet lower than the peaks on each side. Glaciation has materially widened the valley and planed down irregularities throughout nearly the entire length of Middle Fork. The youngest moraines of considerable size are found three miles, or more, from the pass.

The quartz monzonite porphyry—called in this bulletin Etna porphyry—is the most important igneous rock in areal extent in the valley. A prominent characteristic of this rock is the great number of large, pink or reddish phenocrysts of orthoclase (Pl. XI, *B*). The Etna porphyry forms a very irregularly-shaped stock which cuts through the fine-grained quartz latite porphyry. Much volcanic breccia is found on the west rim of the valley together with several large masses of Paleozoic sediments that are inclosed by igneous rocks.

A few ore bodies in fissure veins and at eruptive contacts have been mined in the Middle Fork valley, but thorough prospecting has been retarded by the great amount of sliderock, by the heavy snow which remains nearly throughout the year, and by snowslides.

COLUMBUS AND KANGAROO GULCHES

These very steep gulches, tributary to Middle Fork, are strongly suggestive of hanging valleys. They have been cut chiefly in the late Paleozoic strata which stand nearly vertical. These strata have been cut off by the intrusion of quartz monzonite which is partly within the Columbus valley. Northeastward-striking porphyry dikes are common in both the quartz monzonite and sedimentary areas. By contact metamorphism, the sandstones and shales of the original strata have been changed to quartzite and hornfels.

A few small ore bodies in the sediments and larger ones in the fissure veins in the quartz monzonite have been mined.

NORTH FORK

The North Fork valley may be divided into three parts, each having a length of about three miles. In the lower division the valley is less than a mile wide, rather flat at the bottom, and bordered by high terraces. (See Chap. I.) The middle division is a deep U-shaped canyon formed by stream and glacier erosion. The walls are of pre-Cambrian gneiss for the most part, though granite and quartz monzonite form the walls near the upper end of this division. The upper division includes several tributary valleys as well as about one-third of the main valley. All these valleys head in glacial cirques where lakelets are numerous. Part of the lake basins were formed by glacial gouging; others are the result of morainal damming; a few owe their existence to repeated accumulations of snow at the foot of cliffs or to the combined effects of snow-banks and glaciers. Without doubt the glaciers were very effective in both deepening and widening the valleys. Morainal boulders are abundant in the main valley, particularly in the middle and lower divisions.

The rocks of the upper division include the Pomeroy quartz monzonite, quartz latite porphyry, andesite, and quartz monzonite gneiss. Fissure veins are common in the quartz monzonite. Payable ore has been found in several fissure veins and at one eruptive contact.

BROWNS GULCH

The physiographic features of Browns Gulch are similar to those of North Fork. Glaciers were also very effective agents here in widening and deepening the valley. The canyon walls of the middle division are chiefly of post-Paleozoic granite. Pomeroy quartz monzonite and andesite are the principal rocks of the upper part of the gulch. A small amount of silver-lead ore has been found near the southwest rim of the gulch; molybdenum ore is present on the north side.

TOMICHI DISTRICT

LAKE HILL, WEST POINT, AND PORCUPINE RIDGE

The principal rocks of the general region containing the three localities named are pre-Cambrian granite, Paleozoic sediments, and quartz monzonite. The granite is gray, massive, and almost uniformly porphyritic. Small orthoclase phenocrysts make up more than half the rock mass. The groundmass is composed of quartz, orthoclase, and biotite, all of which can be seen by the naked eye. The quartz monzonite is rarely porphyritic, contains less quartz than the granite, and carries a greater proportion of lustrous biotite. The sediments include the Sawatch quartzite, Tomichi limestone, Ouray limestone, and the lower part of the Garfield formation. These formations are the same as those briefly described in the paragraphs on Monarch Hill and Taylor Gulch, and like the sediments of Taylor Gulch they have been greatly metamorphosed over much of the area. A large quantity of the limestone has been changed to marble, shales have been hardened and locally baked, and massive diopside has been locally formed.

The strata dip eastward at an angle of 30° to 60°. (See Pl. XVI, *B*). Northeast of Lake Hill and Porcupine Ridge the granite has been faulted up against the sediments along the plane of the Morning Glim fault on which the displacement is more than 1,000 feet. The granite underlying the sediments of Lake Hill has been faulted up, along the Star fault, against the eastward-dipping strata of West Point. The displacement here is probably 2,000 feet or more. The lower Paleozoic sediments of West Point overlie the pre-Cambrian granite. On Porcupine Ridge the quartz monzonite is intrusive in these sediments and cuts off the Morning Glim fault.

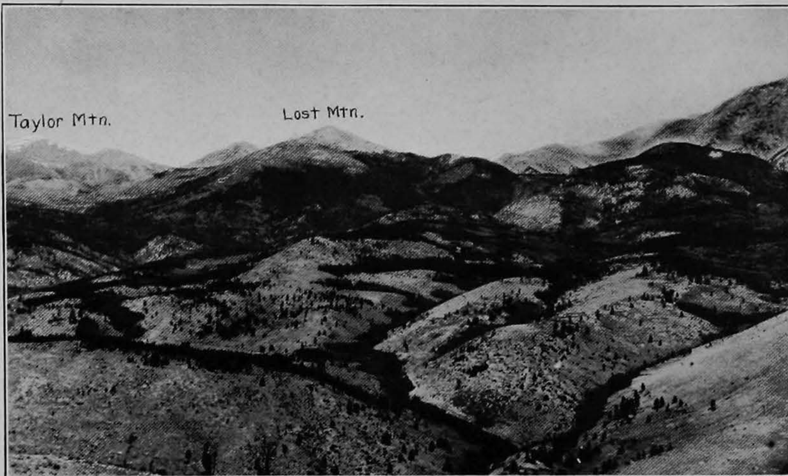
Several dikes of porphyry and pitchstone have been intruded into the sedimentary rocks, and a few short dikes of porphyry are found in the quartz monzonite. One of the dikes follows the Star fault rather closely. Another cuts the sediments near the Morning Glim fault on the west slope of Porcupine Ridge. A few bear no apparent relation to previous structure.

Many morainal boulders may be seen on the slope east of Tomichi Creek several hundred feet above the creek level. These were doubtless deposited by a moraine which moved down the valley but there is no observed evidence of former glaciers in the area described, east of the west slope of West Point.

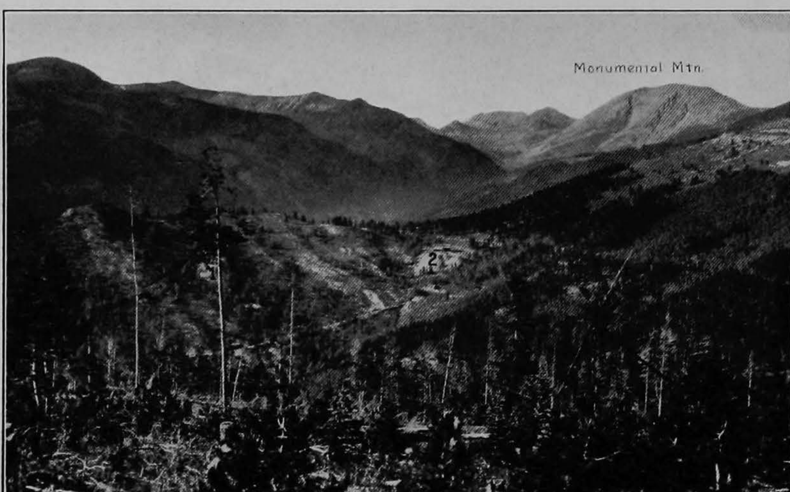
The area described has hitherto been the most productive part of the Tomichi district. The ore bodies are chiefly replacement deposits in the limestone, but the ore of the Spar Copper mine, on Porcupine Ridge, is in a fissure vein in the pre-Cambrian granite.

ROBBINS GULCH

The oldest rock in the valley of Robbins Creek is the pre-Cambrian granite which is exposed over a considerable area on both sides of the creek in the upper two-thirds of its course. North of the creek are remnants of the lower Paleozoic sediments. These have been intruded successively by quartz monzonite gneiss, quartz monzonite, and Etna quartz monzonite porphyry. Volcanic breccia is exposed over a large area north of the upper part of the creek. A small part of two bodies of quartz monzonite is exposed in the valley; these are the Princeton batholith and the Copper Hill stock. Only small masses of the quartz monzonite gneiss may be seen. Debris, slope-wash, and alluvium are abundant, particularly in the lower part of the valley, near Tomichi Creek.



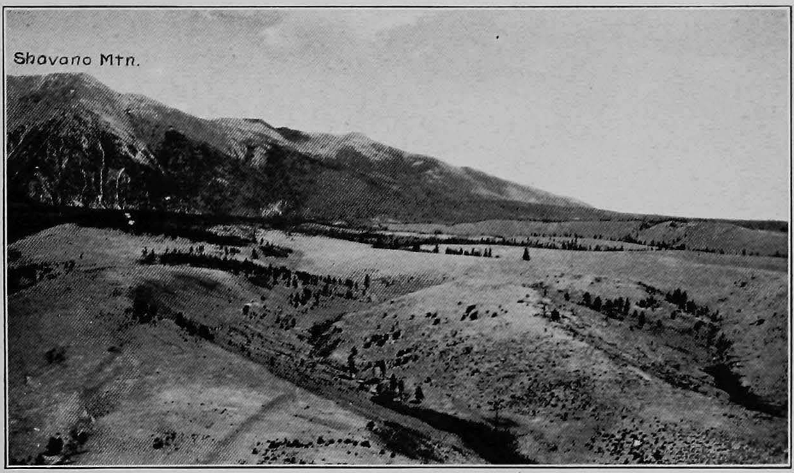
A.—HIGH TERRACES NORTH OF



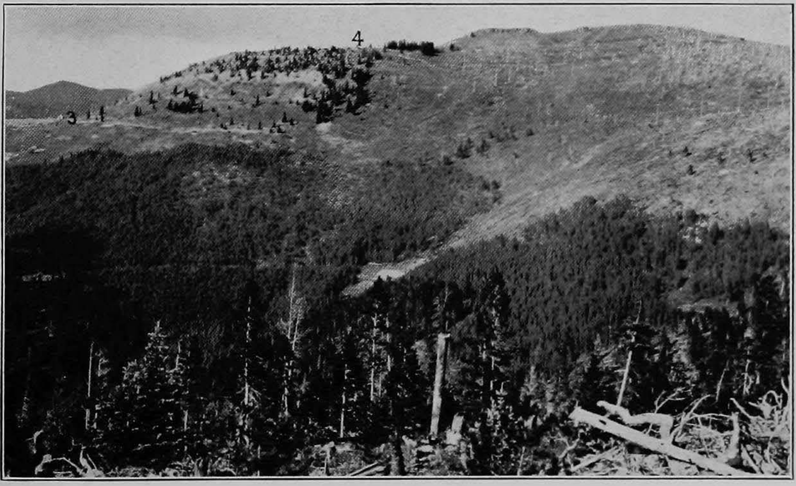
B.—WEST POINT AND LAKE

1. Denver City shaft. 2. Victor shaft in Star fault.

1 and 3 are in approximately the same stratigraphic horizon, but the sediments at 3 have been greatly elevated by faulting at 2.



SOUTH ARKANSAS RIVER



HILL FROM THE SOUTHWEST

3. Breadwinner shaft. 4. David H. mine.

Several mines, in Robbins Gulch, were developed many years ago. The ore was partly in fissure veins in the granite, and partly in the limestone, perhaps as a replacement.

FORT SCOTT GULCH

The geology of this gulch is similar to that of Robbins Gulch. Granite, however, is exposed over a smaller area, while the post-Paleozoic intrusive rocks are more abundant. Pre-Cambrian granite, Paleozoic sediments, quartz monzonite, quartz monzonite porphyry, quartz latite porphyry, and volcanic breccia are all found in the valley. A few carloads of good ore have been shipped from the Fort Scott mine near the head of the gulch.

WEST OF TOMICHI CREEK

West of Tomichi creek the geology is simple. Near the west border of the area mapped massive, porphyritic granite is the only country rock exposed, except near the northwest corner of the district. By far the commonest rock is quartz monzonite, which extends far north beyond the boundary of the district. A remnant of Paleozoic sediments is found northwest of Mount Stella, and a small inclusion of marble in the quartz monzonite outcrops on the south slope of Mount Stella. On the west slope of the same mountain is a stock of quartz diorite. Porphyry dikes are rare. West of the border of the area surveyed, about a mile and a half west of Granite Mountain, the granite is faulted up against the eastward-dipping sediments.

Northeastward-striking fissure veins are common in the quartz monzonite. Though quartz is the commonest vein filling, several workable ore bodies have been discovered.

There is evidence of former small glaciers on the higher slopes, and morainal boulders deposited by the Tomichi Valley glacier are common west of Tomichi Creek.

CHAPTER VIII

PETROGRAPHY OF THE POST-CARBONIFEROUS IGNEOUS ROCKS

In this chapter the rocks are grouped according to their occurrence, namely: (1) rocks of the batholith and stocks, (2) rocks of the chonoliths, (3) dike-rocks, and (4) extrusive rocks. Though this grouping, which is geologic rather than petrographic, brings together rocks which differ greatly in composition and considerably in age, the petrographic relationships are pointed out in the succeeding chapter.

ROCKS OF THE BATHOLITH AND STOCKS

QUARTZ DIORITE

Occurrence. — Fine-grained quartz diorite occurs on the southeast slope of Lost Mountain in a stock whose longest diameter is about a mile and a half; it is also found in a smaller stock on the southwest slope of Mount Stella. A rock, which is somewhat monzonitic, although very similar to the typical quartz diorite in chemical composition, forms a small stock about a mile from Monarch toward the northwest.

Age relations.—Of the three quartz diorite bodies, only one, the Mount Stella stock, is in contact with Paleozoic or later rocks. This stock cuts only the pre-Cambrian granite and the oldest sediments; the beds younger than Ordovician have been removed from this vicinity by erosion or by both erosive and igneous agencies. The quartz monzonite of the batholith is younger than the quartz diorite, as shown by the numerous inclusions of the latter rock in the quartz monzonite on the southwest slope of Mount Stella. It is highly probable that the stocks of Lost Mountain and Mount Stella were intruded at the same time. The Monarch stock, which lithologically differs from the other two, may be a little older or younger.

The quartz diorite is hence one of the oldest post-Ordovician intrusive rocks. There is no reason to believe that it preceded the others by a long period. It was probably the first plutonic rock intruded in the epoch of post-Carboniferous, or Tertiary, vulcanism.[1]

Description.—The fresh, typical quartz diorite is dark bluish-gray, while weathered surfaces are a dull brownish-gray. In the hand specimen the eye can detect feldspar and numerous bright cleavage faces of black mica. The total amount of dark minerals is greater than that of any other post-Carboniferous rock in the district. The grains have an average diameter of less than two millimeters. Along the southeast border of the Lost Mountain stock the rock is a quartz diorite porphyry rather than an even-granular quartz diorite, indicating that cooling along the margin was more rapid—a common phenomenon in small stocks which do not reach the surface at the time of intrusion.

The even-granular diorite is very similar in texture and composition to specimen 93 of the educational series of rock specimens prepared by the United States Geological Survey. The latter rock comes from Teocalli Mountain, Gunnison County, and is described by Cross,[2] who states that it occurs in large stocks with ramifying dikes cutting through Carboniferous strata.

The microscope shows apatite, zircon, iron ore, titanite, pyroxene, hornblende, biotite, plagioclase, orthoclase, and quartz. Apatite is present in minute short crystals. All the zircon crystals are small; although most of them have the usual stout habit, a few comparatively long prisms are present. Black iron ore in octahedrons and formless grains is a constant accessory. Titanite occurs in wedge-shape crystals and anhedrons in a few specimens in very small amount. Some specimens do not show this mineral.

Although the three ferromagnesian constituents—biotite, hornblende, and pyroxene—are everywhere present, the relative amounts are variable. All are without crystal outline and intergrowths of any two are not uncommon. In many instances hornblende or biotite has grown around a core of pyroxene, which is pale-green augite with a wide extinction angle. The augite is present in less amount than either hornblende or biotite. The hornblende is the common green variety with strong pleochroism. In some cases this mineral is found in aggregates of many anhedrons. Brown, pleochroic biotite is the most abundant of the three ferromagnesian minerals.

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[1] See also pp. 75, 144, 178.

[2] Bull. U. S. Geol. Survey No. 150, 1898, pp. 241-243; Anthracite-Crested Butte Folio (No. 9), U. S. Geol. Survey, 1894.

The *plagioclase,* which occurs in the rock in greater quantity than any other mineral, has crystallized in almost automorphic forms. Zonal structure is distinct in many crystals. Pericline or Carlsbad twinning frequently accompanies the common albite twinning. Crystals which combine albite and Carlsbad twins are found by the Michel-Lévy method to be largely andesine ranging from Ab_5An_3 to Ab_1An_1. Many crystals have a more acid shell. In some sections alteration has given rise to a more or less fibrous mineral (probably tremolite) with a birefringence of about 0.027. *Orthoclase* ranges from an almost negligible to a considerable component, but is everywhere greatly subordinate to the plagioclase. In some cases it incloses several of the earlier-formed minerals in poikilitic manner.

Quartz, the last product of crystallization, is constantly present in small amount. It carries, in addition to apatite and zircon, many gas and liquid inclusions, some of which occupy spaces having the form of quartz crystals.

Monzonitic variety.—The rock of the stock near Monarch is lighter in color and slightly coarser in texture than the quartz diorite described. The unaided eye readily recognizes a large proportion of feldspar and abundant lustrous cleavage faces of black mica. The feldspar grains are largely colorless to bluish-gray and commonly have a high luster. With the aid of a lens twinning striæ can sometimes be seen on cleavage faces. In a small area near the west border of the stock the rock is strikingly mottled with alternating light pink and dark greenish-gray patches. The microscope shows the dark patches to be segregations of the dark minerals and plagioclase, while the pink ones are composed principally of orthoclase and quartz.

The microscope shows that the rock of this stock differs from the quartz diorite described chiefly in the slightly larger proportion of orthoclase and smaller proportion of biotite and quartz. Zircon is a conspicuous accessory. The plagioclase crystals are strongly zoned. The greater part of many is labradorite, the core having the composition of approximately Ab_2An_3. The labradorite is surrounded by a shell of acid plagioclase, apparently oligoclase. Other crystals are zoned almost from the center to the border.

Chemical and mineral composition.—Columns 1 and 2 of the table below are analyses of specimens taken from the Lost Mountain stock and the Monarch stock, respectively:

Analyses of quartz diorites

	1	2	3
SiO_2	57.39	57.67	62.71
Al_2O_3	18.26	18.07	17.06
Fe_2O_3	1.58	1.09	3.79
FeO	5.10	4.23	2.74
MgO	1.51	2.69	1.78
CaO	6.52	6.24	5.51
Na_2O	2.78	3.14	3.54
K_2O	4.59	4.02	2.96
H_2O-[1]	.20	.22	...
H_2O+[2]	.11	.17	.24
TiO_2	1.11	1.04	undet.
ZrO_2	.03	.32	...
P_2O_5	.11	.11	none
Cl	.05	.04	...
MnO	.88	.80	trace
	100.22	99.85	100.33

1. Quartz diorite, Lost Mountain, Monarch district, Colorado. R. M. Butters, analyst.
2. Quartz diorite (monzonitic variety), Monarch, Colorado. R. M. Butters, analyst.
3. Diorite, Middle Brush Creek, Gunnison County, Colorado. L. G. Eakins, analyst. Cross, Whitman, Bull. U. S. Geol. Survey No. 150, 1898, p. 242; Bull. U. S. Geol. Survey No. 419, p. 111.

The norms[3] of the two varieties of the rock of the Monarch district are given in the following table:

Norms of quartz diorite of the Monarch district

	1	2
Quartz	5.82	5.16
Orthoclase	27.24	23.91
Albite	23.58	26.72
Anorthite	23.63	23.07
Diopside	6.59	5.97
Hypersthene	8.38	10.35
Magnetite	2.32	1.62
Ilmenite	2.13	1.98
Apatite	.31	.31
Zircon	...	.37
	100.00	99.46

1. Quartz diorite, shoshonose, Lost Mountain, Colorado.
2. Quartz diorite, shoshonose, Monarch, Colorado.

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[1]Below 110° C.; [2]above 110° C.

[3]Cross, Whitman; Iddings, J. P.; Pirsson, L. V., and Washington, H. S., Quantitative classification of igneous rocks, 1903, p. 147.

The actual mineral composition of the Lost Mountain rock was determined by the Rosiwal method, as follows:

Mineral composition[1] *of quartz diorite of Lost Mountain*

Quartz	13.7
Orthoclase	18.9
Plagioclase	39.8
Augite	6.0
Hornblende	4.1
Biotite	15.0
Iron ore	2.4
	99.9

Chemically the rock is probably more nearly a monzonite than a diorite, owing to the excess of potash over soda, the reverse of what is seen in a normal diorite, but the proportion of orthoclase is a little low for a typical monzonite. The development of much biotite, owing perhaps to the high alumina and ferrous oxide, materially reduced the amount of potash available for orthoclase. One might call the monzonitic variety a diorite-monzonite, as Cross[2] has named a somewhat similar rock in the Telluride quadrangle.

POMEROY QUARTZ MONZONITE

Occurrence.—This type of quartz monzonite, here called Pomeroy quartz monzonite to distinguish it from the Princeton type, is exposed in the northwest part of the Monarch district over a wide area which narrows to a mere tongue where it extends into the Tomichi district. The rock forms a stock whose north boundary has not been traced by the writer, but is evidently south of Chalk Creek.

This stock has probably suffered but little from erosion. At the south and southeast margin of the body the surface dips under the younger porphyries at an angle of 25° to 45°. The typical rock near this margin, both below the later porphyries and near the head of North Fork where it has been exposed to erosion, grades into a finer-textured and more acid marginal facies. It is hence inferred that the surface as now exposed is not far from the original upper surface of the stock.

Age relations.—The Pomeroy quartz monzonite is older than the post-Carboniferous granite which, in Browns Gulch, incloses

[1] Total distance measured, 46.44 mm.; number of measurements, 137.
[2] Cross, Whitman, Telluride Folio (No. 57), U. S. Geol. Survey, 1899, p. 6.

a large xenolith of the quartz monzonite penetrated by a dikelet of the granite. It is also older than the dacitic rock which overlies it at Pomeroy Pass, as evidenced by inclusions of the quartz monzonite in the overlying dacitic porphyry. The relation to the Princeton quartz monzonite is not clear, but it is uniform in texture to the west boundary, where it is in contact with the granite porphyry that is probably a marginal facies of the Princeton quartz monzonite. These relations suggest that the Pomeroy quartz monzonite is older than the Princeton quartz monzonite.

Description.—The Pomeroy quartz monzonite is a pinkish-gray to bluish-gray rock in which bluish feldspars with a high luster, pinkish to white lusterless feldspars, chloritized hornblende, and a few biotite crystals can be seen with the naked eye. Occasional quartz grains can be seen under a strong lens. Small grains of pyrite are not uncommon. The light-colored components are greatly in excess of the dark minerals. The bluish feldspar crystals, of which many show albite twinning under a lens, have well developed crystal outlines, while the quartz and part of the unstriated feldspar have crystallized in the interstices.

Near the southeast border of the large area, from Pomeroy Pass northward, there is a facies which carries but little hornblende and biotite and is more noticeably porphyritic. This rock carries a few plagioclase phenocrysts in a fine-grained, granitic groundmass composed largely of orthoclase and quartz. This rock is evidently a border facies into which the typical quartz monzonite grades. It is probable, however, that a few narrow dikes of similar porphyry have been intruded into the quartz monzonite between Grizzly Gulch and North Fork.

Wherever the quartz monzonite near the east border is exposed on the ridges, it is much stained with red and brown oxide of iron. This colored strip may reach a width of 200 feet or more. The bright colors are very conspicuous on Pomeroy Pass and on the divide between Grizzly Gulch and North Fork.

In thin section can be seen zircon, apatite, iron ore, titanite, augite, hornblende, biotite, plagioclase, orthoclase, quartz, and the secondary minerals mentioned below. Zircon, apatite, and titanite are present as accessory minerals in very small amount.

Augite was seen in only one slide, that of a specimen from Chapman Mountain outside of the area mapped. The augite is pale green, has good prismatic cleavage, and extinguishes at about 40°. The *hornblende* is pale green, pleochroic, and frequently chloritized. Unaltered *biotite* is rare. In most cases the biotite is replaced in greater or less degree by chlorite. A few small octahedrons of iron ore, inclosed by the hornblende and biotite, are probably primary. There are, however, associated with the hornblende and biotite, numerous patches of iron ore which probably separated out in the process of chloritization.

The most important mineral in the rock is *plagioclase* which forms almost automorphic crystals. Combinations of Carlsbad and albite twins are common, and afford opportunity for measurements which show the mineral to be labradorite with the composition of approximately Ab_2An_3. This feldspar is apparently uniform in composition as it does not exhibit the zonal banding seen in the other plagioclase-bearing rocks described.

In this rock the *orthoclase* sometimes involves the earlier-formed minerals and not infrequently forms phenocrysts. It has, however, largely crystallized in the interspaces after the formation of the labradorite crystals was practically complete, and almost universally forms beautiful micrographic intergrowths with quartz.

Everywhere on the surface and in the mine workings the rock is greatly weathered. Besides the chlorite and iron ore mentioned, kaolin is common. Small amounts of calcite, epidote, and a colorless mineral, perhaps an amphibole, may be observed in the thin sections.

Chemical and mineral composition.—The analysis of a specimen taken from the dump at the Pride of the West tunnel on the east slope of Pomeroy Mountain, is given in the first column of the following table:

Analyses of quartz monzonites and constituent hornblende and biotite

	1	2	3	4
SiO_2	62.60	66.83	47.49	35.75
Al_2O_3	18.16	15.24	7.07	14.70
Fe_2O_3	.91	2.73	4.88	4.65
FeO	2.72	1.66	10.69	14.08
MgO	.96	1.63	13.06	12.37
CaO	5.30	3.59	11.92	.17
Na_2O	3.02	3.10	.75	.32
K_2O	4.10	4.46	.49	9.19
H_2O-	.28	...	...	1.03
H_2O+	.34	.56	1.86	3.64
TiO_2	1.02	.54	1.21	3.16
ZrO_2	trace	.04	none	none
P_2O_5	.06	.18	...	.03
Cl	.04	.02	...	...
MnO	.50	.10	.51	.45
Remainder	...	.14	.12	.29
	100.01	100.82	100.05	99.83

1. Pomeroy quartz monzonite, Pride of the West tunnel, Pomeroy Mountain, Monarch district, Colorado. R. M. Butters, analyst.

2. Quartz monzonite, Nevada Falls trail, Yosemite Valley, California (average rock of region). Wm. Valentine, analyst. Turner, H. W., Am. Jour. Sci., 4th ser., vol. 7, 1899, p. 297; Quantitative classification of igneous rocks, Table XIIIa; Bull. U. S. Geol. Survey No. 419, 1910, p. 158.

3. Hornblende from variety of 2 rich in hornblende and biotite. W. F. Hillebrand, analyst. Loc. cit.

4. Biotite from same block as 3. W. F. Hillebrand, analyst. Turner, H. W., Am. Jour. Sci., 4th ser., vol. 7, 1899, p. 297; Quantitative classification of igneous rocks, Table XIV; Bull. U. S. Geol. Survey No. 419, 1910, p. 289.

The norm according to the quantitative classification is as follows:

Norm of quartz monzonite of Pomeroy Mountain

Quartz	15.60
Orthoclase	24.46
Albite	25.15
Anorthite	23.85
Diopside	2.30
Hypersthene	4.77
Magnetite	1.39
Ilmenite	1.98
	99.50

This norm corresponds to amiatose.

The following is the actual mineral composition calculated from the chemical analysis:

Mineral composition of quartz monzonite of Pomeroy Mountain

Quartz	17.46
Orthoclase	28.59
Labradorite (about Ab_1An_1)	40.52
Biotite	3.96
Hornblende	6.94
Magnetite	.70
Ilmenite	1.52
	99.69

Thin sections of the rock of Pomeroy Mountain carry no pyroxene. The hornblende and biotite were assumed to have a composition similar to those whose analyses are given in the table on the preceding page. In the calculation it was found that in the combinations used the hornblende and biotite required .86 per cent less ferrous oxide and .48 per cent more magnesia than the chemical analysis of the rock shows.

The orthoclase was assumed to have the same composition as that of the Etna porphyry (p. 158). Since the plagioclase, as calculated from the chemical analysis, contains a smaller proportion of lime than optical determinations indicate, it is not improbable that the orthoclase contains more soda than was assumed and that the true ratio of orthoclase to plagioclase is somewhat greater than that of the table above.

PRINCETON QUARTZ MONZONITE

Name.—Since there are two distinct types of quartz monzonite in the area mapped, it is necessary to give each a distinctive name in this paper for purposes of reference. Because the type here considered is well exposed on Mount Princeton, one of the highest peaks in the general region, the name Princeton quartz monzonite is used.

Occurrence. — Excepting the pre-Cambrian granite, the Princeton quartz monzonite is more important in areal extent in the Monarch and Tomichi districts than any other igneous rock. It is exposed over a large part of the Tomichi district and extends several miles northwest of the limits of the mapped area. A stock approximately half a mile in diameter is found about a mile southwest of Clover Mountain. In the Monarch district it forms a dike-like mass, half a mile to a mile wide, which reaches from near the northeast corner of the district to the north end of the Lake fault. Several small stocks are found in the vicinity

A.—PHOTOMICROGRAPH OF QUARTZ DIORITE FROM LOST MOUNTAIN
Crossed nicols; x 14.

B.—PHOTOMICROGRAPH OF QUARTZ MONZONITE FROM TAYLOR MOUNTAIN
Crossed nicols; x 14.

of Taylor Mountain and Cree Camp. The map also shows a small part of an exposure in Pomeroy Gulch, in the Chalk Creek district.

Excepting the stocks, the occurrences noted are part of a large batholith which lies mostly north of the area mapped. This quartz monzonite is exposed continuously from the foot of the east slope of Mount Princeton to Tincup Pass on the Continental Divide toward the west, a distance of about fifteen miles. It forms the crest of the divide from Tincup Pass toward the north about a mile (estimated). The same rock forms the bulk of Mount Princeton and the ridge extending from this mountain to the Continental Divide. The color of the outcrop at the foot of the southeast slope of Mount Yale on the north side of Cottonwood Creek and the character of the relief as seen from a distance, together with the large proportion of quartz monzonite boulders brought down to Buena Vista by Cottonwood Creek, lead to the inference that the batholith extends at least to the foot of Mount Yale. Boulders of the quartz monzonite were also found by the writer nearly a mile north of Buena Vista, on the bank of the Arkansas River. Since these could not have been brought down by Cottonwood Creek, as its course is at present, it is not unlikely that there is an exposure of the quartz monzonite north of Mount Yale. It is very probable that the batholith is exposed continuously from Mount Yale on the northeast to Spring Creek in the Tomichi district on the southwest, a distance of about twenty miles. The total area exposed is probably not less than 200 square miles, and may be much greater.

A considerable area of the pre-Cambrian granite west of Boss Lake was included with the quartz monzonite on our preliminary map.[1] More detailed work shows that, while the granite dikes from the quartz monzonite extend practically to the lake, the contact between the quartz monzonite itself and the old granite is distant nearly a quarter of a mile. Since from this point northwestward to the foot of Mount Etna the contact is concealed by talus and soil, the position can be shown on the map only approximately. This position cannot be far from correct since the granite is exposed on the north slope of the ridge while the quartz monzonite is in place south of the creek, near the foot of Mount Etna.

Description.—The minerals which can be recognized in hand specimens of the quartz monzonite, are pink and white to bluish

[1] Bulletin 1.

feldspars, quartz, biotite, hornblende, and accessory titanite. On Taylor and Shavano mountains where the fresh rock is exposed, it is generally even-grained, but occasionally a pink feldspar phenocryst, with a maximum diameter of one inch (about 25 mm.), may be seen. Ordinarily the feldspars are less than five or six millimeters in diameter. A few of the pink orthoclase crystals are twinned after the Carlsbad law, and twinning striæ may sometimes be readily seen on the white to bluish plagioclase cleavage faces. The biotite and hornblende crystals are one to three millimeters in diameter. Although quartz is always present, it is subordinate in quantity, and in some cases almost disappears. Titanite is a constant and conspicuous accessory in yellow crystals one to three millimeters long. Everywhere the dark minerals are subordinate in quantity to the feldspars, but are prominent wherever their luster has not been dulled by weathering. The fresh rock is commonly pinkish-gray but in some weathered exposures is nearly white. Over considerable areas, and especially where it is much weathered, the quartz monzonite might readily be taken for a quartz-poor granite. Where it is intruded into the pre-Cambrian granite it is often difficult to distinguish one rock from the other. In the Tomichi district, particularly west and northwest of Whitepine, orthoclase is less abundant while plagioclase, commonly bluish here, increases in quantity.

Though there has been but little differentiation in the quartz monzonite batholith, the rock along Chalk Creek seems to be somewhat poorer in ferromagnesian minerals and richer in feldspar and quartz than the same rock in the Monarch and Tomichi districts. Specimens from Tincup Pass are practically identical with those from Taylor Mountain.

Thin sections of the quartz monzonite show apatite, zircon, iron ore, titanite, pyroxene, hornblende, biotite, plagioclase, orthoclase, and quartz.

Apatite and zircon occur in their usual forms. Black iron ore is commonly associated with, or inclosed by, both hornblende and biotite and is in part secondary. Considerable pyrite may be seen in the quartz monzonite near the diorite stock southwest of Mount Stella. Titanite, the most abundant accessory, is present in wedge-shaped crystals and irregular grains. Its period of crystallization appears to have been drawn out to considerable length. One slide with an unusual quantity of titanite shows an irregular mass filling a space between orthoclase grains which are automorphic toward the titanite. It is possible that in this case the titanite is a secondary mineral.

Of the large number of sections examined, only one showed *pyroxene* which is a very pale-green monoclinic variety. *Hornblende* and *biotite* are present in nearly equal amounts, and are intergrown in many cases. They have crystallized in part earlier, in part later, than the plagioclase, but are automorphic toward the orthoclase. The hornblende is not infrequently twinned.

Plagioclase is in excess of orthoclase in many specimens, but the proportion is not constant. Since the plagioclase is usually in smaller crystals than the orthoclase it is less likely to be lost in grinding than is the orthoclase. Hence a study of the thin sections, without comparison with the hand specimens, would probably give an erroneous idea of the relative importance of the plagioclase. As is usual in rocks of this character, this mineral shows a strong tendency toward automorphism. Zonal banding is pronounced. A few crystals inclose many flakes of biotite. Combinations of Carlsbad and albite twins are comparatively rare—a fact which makes difficult the specific determination of the feldspar. The individuals which lend themselves to measurement are andesine-labradorite with the composition of approximately Ab_4An_3 to Ab_2An_3. In some cases a narrow border of albite or oligoclase surrounds the less sodic core. The *orthoclase* commonly presents no crystal outline and poikilitically incloses all of the earlier-formed minerals. Carlsbad twins are occasionally seen.

Quartz is everywhere present, though in very small quantity in some specimens. Micrographic intergrowths of quartz and orthoclase are rarely seen.

Marginal facies.—There seems to be very little change in the composition and texture of the Princeton quartz monzonite in most places as the border is approached, except in the Chalk Creek district near the Pomeroy quartz monzonite. Here, while the rock for several hundred feet is more granitic in composition, it evidently passes, toward the northwest, into the typical quartz monzonite by the gradual increase of plagioclase and decrease of orthoclase and quartz.

This marginal facies is porphyritic, having phenocrysts of pink orthoclase, greenish-white plagioclase, and biotite. The phanerocrystalline groundmass is composed essentially of graphically intergrown quartz and orthoclase. This variety is separated from the Pomeroy quartz monzonite by a granite porphyry zone several yards wide. The granite porphyry carries phenocrysts of orthoclase, plagioclase, and biotite in a fine-granular to microgranular groundmass composed chiefly of quartz and orthoclase. There is evidently a sharp contact between this porphyry and the Pomeroy quartz monzonite, but the relation to the granitic facies of the Princeton quartz monzonite is not quite clear. The granite porphyry is very probably an extreme marginal facies of the Princeton quartz monzonite, yet it may possibly be a later intrusion.

Structure.—Nearly everywhere the Princeton quartz monzonite is massive and shows no evidence of regional metamorphism. On the south slope of Mount Etna, however, shearing stresses have produced a slight directional structure and numerous small fractures. Farther northeast the same rock, in contact with the wide dike of porphyry, has undergone shearing and fracturing, with much grinding. No regular system of jointing has been observed. Joint-blocks of any size up to fifteen feet in diameter may be seen.

West and northwest of Whitepine, in the Chalk Creek district, and on the southwest slope of Taylor Mountain, are a number of quartz veins filling fissures which were probably formed by the contraction of the quartz monzonite while it was crystallizing and cooling. Several workable ore bodies have been discovered in these veins.

Inclusions.—On the northeast shoulder of Taylor Mountain the quartz monzonite incloses a block of the Paleozoic sediments several feet across. Southeast of Mount Stella, in the vicinity of the diorite stock, from the contact to half a mile distant, small, angular fragments of dark, fine-grained rock may be seen in the monzonite. These are very probably fragments of the diorite picked up by the monzonite at the time of intrusion.

Another class of dark-colored inclusions occasionally seen, especially on Taylor Mountain, shows in thin section a larger proportion of biotite, hornblende, plagioclase, and apatite than is found in the inclosing rock. These inclusions are from an inch to a few inches in diameter. Unlike the inclusions of quartz diorite mentioned above, they have curved outlines and grade, though rapidly, into the quartz monzonite. Their composition and the nature of their boundaries indicate that they are segregations of the earlier-formed minerals in the monzonitic magma, that is, "basic secretions."

Apophyses and complementary dikes.—On the south and east slopes of Taylor Mountain and north of Boss Lake apophyses from the quartz monzonite mass extend into the sedimentary rocks. In some cases these dikes are roughly parallel to the border of the parent body and in a few instances there is no observed connection with the main body at the surface. The rock of most of these dikes is finer in texture and more acidic than the main mass. It ranges from a biotite granite to alaskite. Inclusions of the sedimentary rocks are common. Some of these dikes, even though but a few feet wide, carry parallel dikes or veins of pegmatite. Pegmatite veins extend also into the contact-metamorphosed sedimentary rocks, where they may be from a fraction of an inch to a foot or more in width. Examples of this may be seen on the south wall of the spillway of Boss Lake, where the largest vein varies in width from three to ten inches. This vein shows feldspar with a little quartz at the sides, and, at the center, quartz with a little feldspar together with black tourmaline, biotite, and muscovite.

In the exposures of quartz monzonite proper, pegmatite dikes were not observed. There are, however, occasional narrow dikes of aplite composed essentially of xenomorphic grains of quartz and alkali feldspar. In the one thin section examined, an aggregate of a few grains of pyroxene having the double refraction of diopside, was seen.

Age relations.—The quartz monzonite is intrusive into the youngest consolidated sediments in the region and is therefore much younger than the known Pennsylvanian. Since it incloses fragments of the quartz diorite of Mount Stella and has caused fracturing and shearing of the quartz monzonite gneiss at the contact it was intruded subsequently to both of the rocks named. It is older than the post-Carboniferous granite which incloses masses of the quartz monzonite into which dikelets of the granite penetrate. The existence of marginal facies in Grizzly and Pomeroy gulches suggests that it was intruded later than the Pomeroy quartz monzonite.

Chemical and mineral composition.—The analysis of a specimen of the quartz monzonite of Taylor Mountain is given in column 1 of the table below. The analysis of one of Brögger's[1] typical quartz monzonites is given in column 2.

Analyses of quartz monzonites

	1	2		1	2
SiO_2	67.64	68.97	H_2O-	.13	.70 (H₂O− and H₂O+ together)
Al_2O_3	14.75	14.80	H_2O+	.19	
Fe_2O_3	.81	3.29 (Fe₂O₃ and FeO together)	TiO_2	1.36	...
FeO	1.95		ZrO_2	trace	...
MgO	.94	1.15	P_2O_5	.20	...
CaO	3.98	3.82	Cl	.08	...
Na_2O	3.40	2.46	MnO	.27	...
K_2O	4.06	4.53		99.76	

1. Princeton quartz monzonite, Taylor Mountain, Monarch district, Colorado. R. M. Butters, analyst.

2. Adamellite (quartz monzonite), Landsberg bei Barr, Vogesen, Unger (Rosenbusch). Brögger, W. C., loc. cit.

The norm is as follows:

Norm of quartz monzonite of Taylor Mountain

Quartz	23.16
Orthoclase	24.46
Albite	28.82
Anorthite	12.79
Diopside	4.94
Hypersthene	1.20
Magnetite	1.16
Ilmenite	2.60
Apatite	.31
	99.44

In the quantitative system the rock is toscanose.

The actual mineral composition in percentages by weight, as determined by the Rosiwal method, is given in the table below. For the microscopic measurements, four thin sections, taken from the specimen analyzed, were used. One of these had an average diameter of two centimeters while the others were considerably smaller. A total distance of 173.94 mm. was covered in 352 measurements.

[1] Brögger, W. C., Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, p. 62.

Mineral composition of quartz monzonite of Taylor Mountain

Quartz	18.8
Orthoclase	25.8
Plagioclase	42.5
Hornblende	2.9
Biotite	8.2
Iron ore	1.2
Titanite	.6
	100.0

It is probable that the titanite for the average rock is somewhat higher than determined. Some of the specimens from other parts of the region are somewhat more dioritic than the specimen analyzed. Although this rock contains more plagioclase than Brögger's typical quartz monzonite, it easily comes within the limits of quartz monzonite as the term is now used by the United States Geological Survey. The writer would prefer the much abused, sometimes restricted, and now seldom used name *granodiorite* for a rock of this character.

QUARTZ MONZONITE GNEISS

Distribution.—A body of this rock extends from the south slope of Mount Etna northeastward over five miles into the margin of Browns Gulch. The exposure is continuous, excepting a small area northwest of Taylor Mountain and another area in the vicinity of Shavano, where debris covers the surface. A narrow strip of the same gneiss can be traced from the southwest slope of Shavano Mountain toward the northeast about four miles. Several small masses of the same rock are inclosed by the breccia and porphyry north of Clover Mountain. What is probably a facies of the same rock is seen on the northeast slope of Clover Mountain. Several smaller masses, one of which is shown on the map, are inclosed by the andesite on the south and west slopes of Calico Mountain.

That the gneiss was originally of much greater extent than at present, is indicated by the separation of the two largest bodies by a later intrusion of quartz monzonite and by the occurrence of many inclusions of the gneiss in the younger rocks, over a considerable area.

Age.—The gneiss is clearly older than the Princeton quartz monzonite, as shown by the sheared and granulated character of the gneiss in contact with the monzonite. On the divide near the extreme northeast corner of the largest gneiss area, a small body of massive quartz monzonite may be seen between the gneiss and the wide dike of porphyry. For fifty feet or more from the monzonite, the gneiss is much fractured and has almost completely lost its original directional structure. The gneiss has a similar character on the ridge east of Jennings Gulch where it is in contact with the massive quartz monzonite. In the first examination on the east slope of Mount Etna the gneiss was supposed to be a border facies of the massive quartz monzonite,[1] but observation over wider areas, including exposures at the contact, and also microscopic study, show the two rocks to be distinct from each other.

On the southwest slope of Calico Mountain the gneiss is in eruptive contact with quartzite and baked shale, which are penetrated by apophyses of the gneiss stock. The shale, aside from its extreme alteration, is lithologically similar to the Pennsylvanian shale on Syncline Hill. It is almost certainly not older than Pennsylvanian, since nowhere in the sedimentary areas of the region has older shale been seen, excepting a few thinner Paleozoic strata. The occurrence of a large inclusion of probable Ouray limestone about a quarter of a mile down the slope also suggests that the shale on Calico Mountain is of Pennsylvanian age. From these observations it is concluded that the gneiss is at least younger than the early Pennsylvanian and may be much younger.

Further evidence, though not proof, that the gneiss is younger than the Paleozoic sediments is found in other parts of the district. On the south slope of Mount Etna the gneiss is exposed but a few yards north of an outcrop of metamorphosed sediments. The contact between the two is concealed by debris, but when the structure of the region as a whole is considered, the evidence is strong that this sedimentary remnant was once a part of a westward-dipping series which did not overlie the gneiss. North of Clover Mountain large masses of gneiss are inclosed by the breccia in close proximity to masses of sedimentary rocks which are probably late Paleozoic. Not far east of the largest body of gneiss is part of the westward-dipping limb of what was once a syncline. Although the gneiss is now separated from the

[1] Bull. 1, Colo. Geol. Survey, p. 18.

sedimentary rocks by a later intrusion of quartz monzonite, the relationships are such that Paleozoic sediments must have once occupied the present position of much of the gneiss. The facts observed point to the conclusion that the gneiss came into its present position subsequently to, or synchronously with, the folding of the Paleozoic beds.

Description.—The megascopic constituents of the gneiss are predominant gray to white feldspar, much quartz, and some biotite. Everywhere, excepting near the contact with later intrusives, the rock is distinctly foliated. The light minerals are in lens-like forms, many of which are two inches in diameter, although most of them are smaller; the longest diameter of a few lenses is about three inches. The biotite occurs in bands and more or less lenticular aggregates (Pl. XI). The rock has a far coarser texture than any other in the district, excepting the pegmatite. The great majority of the light-colored lenses are made up of granular aggregates of feldspar or feldspar and quartz. Not a few are composed of a single individual of feldspar, ungranulated, excepting where it is more or less pinched at the extremities. A few single ungranulated phenocrystic feldspars show automorphic forms. Several of the last two varieties were noticed composed of single crystals two to three inches long and one-half to three-quarters of an inch thick. The ungranulated character is shown by the uniform reflection of light from a single cleavage face extending nearly or quite across the crystal. A few crystals are twinned after the Carlsbad law.

The direction of easiest cleavage of the rock is, in general, roughly parallel to the wide dike of porphyry which separates the largest body of gneiss from the Princeton quartz monzonite. A record was kept of a large number of determinations of the dip and strike of the foliation. The strike mainly varies from N. 10° W. to N. 40° E.; the dip is commonly between 50° and 90° westward. There are local deviations from the range of dip and strike given, near the quartz monzonite contact east of the head of Jennings Gulch where in one instance the foliation dips 30° S. 60° E.

In texture and structure this rock resembles a porphyritic granite gneiss ("Stony Creek granite gneiss") quarried at Hoadly

Point, Connecticut, and described by Gregory,[1] by Loughlin,[2] and by Dale and Gregory.[3] A photograph of specimens of the Connecticut rock shown on Plate IV of Dale and Gregory's report could scarcely be distinguished from photographs of selected specimens of the Monarch gneiss.

In thin section zircon, apatite, titanite, allanite, iron ore, hornblende, biotite, plagioclase, orthoclase, microcline, and quartz are seen.

Zircon and apatite occur in almost negligible quantity; a few of the apatites are long and needle-like. Titanite is a plentiful accessory in anhedrons of considerable size. Allanite is rare in small, pleochroic grains. Black iron ore varies greatly in amount in different slides and is largely secondary. It is partly magnetite which shows only a weak titanium reaction.

In the slides examined, *hornblende* is present in less quantity than allanite. Only one crystal was seen. This is bright green and strongly pleochroic. The brown, pleochroic biotite is more or less altered to chlorite with separated magnetite.

Plagioclase is probably somewhat in excess of potash feldspar in the sections studied. It is practically homogeneous as shown by the absence of zonal structure. A combination of pericline and albite twinning is seen in the majority of individuals. Carlsbad twins are combined with one or both of the other varieties of twins in a few grains. Measurements according to the Michel-Lévy method show the plagioclase to be andesine having the composition of about Ab_2An_1.

Orthoclase and *microcline* form the largest grains and phenocrysts of the rock. Near the border of the orthoclase grains micrographic intergrowths with quartz are common, although on a minute scale. The quartz carries abundant liquid inclusions and generally shows undulatory extinction.

Contact phenomena.—On the southwest slope of Calico Mountain the gneiss may be seen in contact with baked shale whose baking was doubtless effected by the heat of the quartz monzonite gneiss intrusion. All the shale of this area seems to be equally affected whether at the immediate contact or distant 100 feet or more. Dikes and sheets, apophyses of the gneiss

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[1] Rice, W. N., and Gregory, H. E., Manual of the geology of Connecticut; Conn. State Geol. and Nat. Hist. Survey, 1906, Bull. 6, p. 147.

[2] Barrell, Joseph, and Loughlin, G. F., The lithology of Connecticut: Conn State Geol. and Nat. Hist. Survey, 1910, Bull. 13, p. 174.

[3] Dale, T. N., and Gregory, H. E., The granites of Connecticut: Bull. U. S Geol. Survey No. 484, 1911, pp. 24, 85, and Pl. IV, A.

stock, penetrate the sediments. These dikes and sheets range in thickness from two to thirty feet, or more. The texture of the rock in these apophyses ranges from fairly coarse gneiss to a porphyry having large feldspar and quartz phenocrysts in a fine-granular groundmass. The gneiss of the rock itself at the immediate contact, differs little, if any, from the typical gneiss described.

Clover Mountain variety.—The small area mapped as quartz monzonite gneiss on the northeast slope of Clover Mountain is more dioritic in appearance than the type described, though it is probably a facies of the same rock. It is composed essentially of feldspar, quartz, and much biotite. Megascopically it resembles the "pinto diorite" of the Little Belt Mountains, Montana, described by Pirsson,[1] but probably has a more pronounced directional structure.

Microscopically it differs from the gneiss described in the arrangement of the biotite and the character of the feldspars. Although the biotite aggregates tend to rough parallelism, more noticeable are the ring-like forms of these aggregates, suggesting an accommodation to the small spheroidal masses of quartz and feldspar. The feldspar is largely plagioclase with very thin albite lamellæ and low extinction angles. Orthoclase and microcline are present in very small quantity. Much alteration of the feldspars and biotite has given rise to kaolin, epidote, chlorite, and iron ore.

Cause of foliation.—Although the gneiss is everywhere distinctly foliated, except locally near the Princeton quartz monzonite where it has lost its original directional structure, it nowhere possesses the folded or contorted character so often seen in the highly metamorphosed pre-Cambrian gneisses. The observations noted in the following paragraphs indicate that the directional structure was brought about, in large part, by the flow of the magma while in a viscous and partly crystallized state.

1. The planes of foliation are roughly parallel to the southeast contact of the stock, which probably has now very nearly the same dip and strike that the contact had when the gneiss was first intruded.

[1] Pirsson, L. V., Petrography of the igneous rocks of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 488.

2. The pre-Cambrian granite on and near Missouri Hill, within a mile of the gneiss, shows little or no gneissoid structure. Wherever the pre-Cambrian granite is gneissoid in this region, it is only in small areas.

3. On Calico Mountain the gneissic rock is found in immediate contact with Paleozoic shales which furnish no evidence of pronounced dynamic metamorphism. Had dynamic forces imposed on the igneous rock its gneissoid structure after the rock had cooled, it is highly probable that a slaty cleavage would have been simultaneously developed in the shales.

4. Large, uncrushed feldspar crystals with their long diameters in the plane of foliation, when taken with the many nearly granular lenses of feldspar, indicate that movement occurred after crystallization was well begun. Evidently crystals which had formed with their long diameters inclined at a high angle to the direction of flow, or movement, were rotated and more or less crushed, while those which were oriented in the direction of movement escaped distortion.

That there has also been some slight dynamic metamorphism of the rock since crystallization was complete, is indicated by the undulatory extinction of the quartz and the presence of much microcline. The lenticular character of the rock might be attributed to severe dynamic stresses after complete crystallization if the geologic relations did not make such an origin improbable.

Chemical and mineral composition.—The following is the analysis of a specimen of quartz monzonite gneiss taken from a prospect in Jennings Gulch:

Analysis of quartz monzonite gneiss of Jennings Gulch
[R. M. Butters, Analyst]

SiO_2	67.90	H_2O-	0.14
Al_2O_3	16.08	H_2O+	0.21
Fe_2O_3	0.83	TiO_2	1.15
FeO	2.02	ZrO_2	trace
MgO	0.73	P_2O_5	0.12
CaO	2.86	Cl	0.01
Na_2O	4.08	MnO	none
K_2O	4.11		
			100.24

The norm of the quartz monzonite gneiss, according to the quantitative system, is as follows:

Norm of quartz monzonite gneiss of Jennings Gulch

Quartz	20.94
Orthoclase	24.46
Albite	34.58
Anorthite	13.34
Hypersthene	2.99
Magnetite	1.16
Ilmenite	2.13
Apatite	0.31
	99.91

This norm corresponds to toscanose.

The mode, or actual mineral composition, calculated from the chemical analysis, is given below. In the calculation enough soda was used to satisfy the lime in the formation of andesine having the composition of Ab_2An_1, since optical determinations show the plagioclase to have approximately this composition. The rest of the soda was combined, in the calculation, with potash in the alkalic feldspar.

Mineral composition of quartz monzonite gneiss of Jennings Gulch

Quartz	22.86
Alkalic feldspar	31.57
Andesine, Ab_2An_1	36.09
Biotite	6.52
Titanite	0.59
Magnetite	0.70
Ilmenite	1.22
Apatite	0.31
	99.86

GRANITE

Granite is exposed on both sides of Browns Gulch near the north border of the field. Its boundary was not traced beyond the limits of the map, but the color contrast on Antero and White mountains, as seen from a distance, would indicate that the granite is in contact with the Princeton quartz monzonite about a mile and a half or two miles north of Browns Gulch. A smaller stock is found north of North Fork.

Age relations.—South of Browns Creek, near the contact between the granite and Princeton quartz monzonite, are boulders which show the granite porphyry facies of the granite in dikelets penetrating the quartz monzonite. North of the creek in the granite is a large xenolith of the same quartz monzonite penetrated by numerous dikelets of granite. In Browns Gulch a large mass of Pomeroy quartz monzonite which is surrounded by the granite, is also cut by a dikelet of the granite. From these observations it is inferred that the granite is younger than both types of quartz monzonite.

Description.—The granite is coarse in texture, having a large proportion of the grains over five millimeters in diameter. White feldspar with sometimes a pink tinge, quartz, and biotite can readily be seen with the naked eye. Feldspar composes nearly two-thirds of the rock and quartz is abundant, while biotite is present in small quantity. As far as observed the granite is massive with no megascopic evidence of dynamic metamorphism. It is commonly even-granular, but near the west border at the north side of Browns Gulch a facies carries small quartz phenocrysts in a groundmass almost phanerocrystalline.

The very light color, almost white, is noticeable for a long distance; the glare at short range in the sunlight is extreme. Weathering has produced, on the gentler slopes, angular fragments of feldspar and of quartz which, in water-courses, form a bed of almost dazzling whiteness.

The granite on White Mountain has furnished crystals of beryl, phenacite, topaz, and other minerals which, according to Sterrett,[1] occur in miarolitic cavities. Just north of Browns Gulch in the area surveyed were found fragments of granite carrying small crystals of beryl and quartz. The shape and arrangement of these crystals point to their formation in a cavity.

Thin sections of the granite show apatite, zircon, titanite, biotite, plagioclase, microperthite, potash feldspars, and quartz, besides secondary iron ore, chlorite, and muscovite.

Apatite is very rare in minute crystals. Zircon is present in small prismatic crystals about five times as long as thick. The titanite is much altered to a yellowish substance bordered by black iron ore.

Biotite is relatively unimportant and has the usual appearance of biotite of ordinary granites. Alteration has given rise to chlorite and iron ore in some flakes; in others, muscovite and iron ore have been formed. A few individuals show chlorite alternating with muscovite.

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[1] Sterrett, D. B., Precious stones: Mineral Resources U. S. for 1908, U. S. Geol. Survey, pt. 2, 1909, pp. 809-811.

Plagioclase is abundant and scarcely exceeded by the combined amounts of orthoclase and microcline in the slides examined. It forms individual anhedrons and is also microperthitically intergrown with orthoclase and microcline. Carlsbad twins can be detected with difficulty, except in sections inclined to the zone (100) (001). Two individuals were noted which combine albite and Carlsbad twins; they have practically parallel extinction and show very slight difference in color between the Carlsbad halves when rotated 45° from the position of extinction. These might be either albite sections normal to (100) (010) or oligoclase. Several other sections normal to the albite lamellæ, and showing no Carlsbad twinning, extinguish at 10° to 15°. The highest index of refraction, as determined by the Becke method, is less than the mean refractive index of quartz. These are properties of albite; the chemical analysis shows that it contains an admixture of the anorthite molecule.

Orthoclase appears in less quantity than either albite or microcline. It is occasionally twinned after the Carlsbad law. The extremely fine twinning of the *microcline* suggests a soda variety. This feldspar is more generally intergrown with albite than is the orthoclase in the slides examined. A small quantity of sericite has been developed through the weathering of all the feldspars. The quartz forms micrographic intergrowths with all the feldspars, though not commonly with the albite. Liquid inclusions are common. A few grains show undulatory extinction as the result of slight dynamic stresses.

Chemical and mineral composition.—In the table below are given the analysis of a specimen of the granite from Browns Gulch and the analysis of the nevadite, or granite porphyry, of Chalk Mountain, in the Leadville region. Specimens of the Chalk Mountain rock and of the granite porphyry marginal facies of the Browns Gulch granite are megascopically very similar.

Analyses of granites and granite porphyry

	1	2	3
SiO_2	74.27	74.40	74.45
Al_2O_3	13.67	13.91	14.72
Fe_2O_3	0.48	1.39	none
FeO	0.45	...	0.56
MgO	0.12	0.28	0.37
CaO	0.65	0.61	0.83
Na_2O	3.48	4.65	3.97
K_2O	5.90	4.36	4.53
H_2O-	0.10	} 0.65[1]	0.66
H_2O+	0.04		
TiO_2	0.49	...	...
ZrO_2	0.01	...	...
P_2O_5	0.04	...	0.01
Cl	0.02	...	...
MnO	none	...	0.28
	99.72	100.25	100.38

1. Granite, Browns Gulch, Colo. R. M. Butters, analyst.

2. Alkali granite with some amphibole and pyroxene. Ragunda, Jemtland, Sweden. Rosenbusch, H., Elemente der Gesteinslehre, 3d ed., 1910, p. 86.

3. Nevadite (granite porphyry), Chalk Mountain, Colo. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 349; Bull. U. S. Geol. Survey No. 150, 1898, p. 164; Clarke, F. W., Bull. U. S. Geol. Survey No. 419, 1910, p. 109.

Rosenbusch[2] objects to the name alkali granite for a rock having this chemical composition, unless it carries alkalic amphiboles or pyroxenes. Professor Pirsson[3] sees no objection to calling such a rock an alkalic granite when we know the chemical and mineral composition, independently of the evidence furnished by the presence of alkalic amphiboles or pyroxenes. He would consider this rock an alkalic, potassic granite, in which biotite has been developed instead of alkalic amphiboles, owing to the high content of potash and conditions of crystallization, whereas in strongly sodic magmas alkali amphiboles or pyroxenes are commonly formed.

The following is the norm of this granite according to the quantitative system:

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[1] Loss on ignition.

[2] Rosenbusch, H., Mikroscopische Physiographie der massige Gesteine, 4th ed., 1907, vol. 2, p. 71.

[3] Personal communication.

Norm of granite of Browns Gulch

Quartz	29.82
Orthoclase	35.03
Albite	29.34
Anorthite	3.34
Hypersthene	0.40
Hematite	0.48
Corundum	0.31
	99.63

This norm corresponds to liparose.

The mode, or actual mineral composition, of the granite, as computed from the chemical analysis, is as follows:

Mineral composition of granite of Browns Gulch

Quartz	30.36
Alkalic feldspar[1]	65.48
Biotite	2.86
Ilmenite	0.15
Titanite	0.78
	99.63

The biotite was assumed to have a composition similar to that noted on page 137. In the calculation it was necessary to make a slight readjustment among the molecules of magnesia, ferrous oxide, and ferric oxide. There was also an excess of .61 per cent alumina which was included in the biotite, in the calculation.

ETNA QUARTZ MONZONITE PORPHYRY

Name.—For purposes of reference, the prefix Etna is here used to distinguish the commonest type of quartz monzonite porphyry, whose occurrence is stated below, from the several varieties found in small stocks and narrow dikes in the area mapped. The Etna quartz monzonite porphyry is often locally called Etna granite.

Occurrence.—The bulk of Mount Etna and Monumental Mountain is composed of quartz monzonite porphyry which forms an irregularly shaped stock more than two miles in diameter. A much smaller stock is found northeast of Tomichi. The same rock forms a strong dike extending northeast and southwest from the largest stock. The width of this dike varies from a few feet to several hundred feet, while the distance between the extremities is

[1] Orthoclase molecule 33.92, albite molecule 29.34, anorthite molecule 2.22.

about eight and one-half miles. The rock of a few small dikes is very similar to the Etna porphyry.

Age relations.—This rock is clearly younger than the Princeton quartz monzonite and the quartz latite porphyry. At two different points between North Fork and Browns Gulch the wide dike breaks through the quartz monzonite. The quartz monzonite, at these points and elsewhere near the contact with the porphyry dike, has been considerably sheared and fractured. It also contains, in several places, dark, narrow streaks of aphanitic rock which may possibly be crushed quartz monzonite, but is more probably material that was injected along fracture lines at the time of the porphyry intrusion.

On the slopes of Monumental Mountain are frequently seen boulders in which the quartz monzonite porphyry incloses small fragments of quartz latite porphyry. High on the southwest slope of the same mountain, near the trail shown on the map, at the contact between the two rocks, dikelets of the coarse quartz monzonite porphyry are seen penetrating the much finer-textured quartz latite porphyry.

Description.—This porphyry shows megascopic orthoclase, plagioclase, quartz, biotite, hornblende, and titanite. Orthoclase forms the largest phenocrysts, which have a diameter of less than half an inch to two inches (about 10 to 50 mm.). The average is probably a little less than one inch. These phenocrysts are commonly pink, but are bluish in parts of the dike north of North Fork. Carlsbad twins are sometimes seen. Some crystals of orthoclase inclose megascopic crystals of the other constituents. In the interspaces among the orthoclase phenocrysts are crystals of plagioclase, quartz, biotite, and hornblende, with a small quantity of groundmass. This is by far the coarsest-grained porphyry in the region mapped. (See Pl. XI.) The plagioclase phenocrysts, which are white to bluish, are commonly less than ten millimeters in diameter. Both Carlsbad and albite twins can be seen in some crystals with the naked eye. The quartz phenocrysts have a slightly larger average size than the plagioclase, but constitute a far smaller volume. The orthoclase, plagioclase, and hornblende phenocrysts have well-developed crystal forms; the quartzes are commonly rounded by resorption.

In most of the thin sections iron ore, titanite, hornblende, biotite, quartz, plagioclase, and alkalic feldspar are seen. Apatite and zircon are less common. Iron ore and titanite have their usual habit.

The phenocrystic *hornblende* forms small automorphic crystals. It is ordinarily bright green, but a few crystals are brown. *Biotite* is present in ragged flakes and in well-defined crystals with hexagonal outline. Hornblende and biotite vary greatly in relative amount. Here one, there the other, dominates.

The *plagioclase* phenocrysts micropoikilitically inclose crystals of titanite and iron ore, flakes of biotite, and grains of quartz. The common albite twinning is combined in some crystals with Carlsbad twins, giving an opportunity to determine specifically the feldspar by the Michel-Lévy method. Crystals so determined are, at the center, labradorite having the composition Ab_1An_1 to Ab_2An_3. Some crystals have an outer zone of more acid feldspar. Zoned crystals are common, but, as a rule, there is very little difference in the composition of different zones.

The *orthoclase* phenocrysts, aside from the numerous inclusions, are homogeneous, but the chemical analysis shows considerable soda. Clinopinacoidal sections extinguish at $+9°$ from the trace of the basal cleavage. The position and small size of the plagioclase crystals, as seen in the hand specimen, suggest that they had crystallized after the orthoclase. But their automorphic forms and common occurrence as inclusions in the orthoclase crystals indicate that crystallization of the plagioclase was, in large part, prior to that of the orthoclase.

The *quartz* phenocrysts are rounded and embayed by resolution. They show inclusions of apatite, zircon, hornblende, groundmass, and liquid.

The *groundmass* is variable in habit. It is mainly composed of quartz and orthoclase, with small quantities of plagioclase, biotite, and hornblende. It is largely microgranitic, but micrographic intergrowths of quartz and orthoclase are not uncommon.

Chemical and mineral composition.—Column 1 of the table below is the analysis of a specimen taken from a prospect on the northeast slope of Clover Mountain. Column 2 shows the composition of a somewhat similar but finer-grained porphyry from the Breckenridge district, Colorado.

Analyses of quartz monzonite porphyries and orthoclase

	1	2	3	4	5
SiO_2	66.71	68.14	63.20	65.04	64.7
Al_2O_3	15.04	15.29	19.58	20.40	18.4
Fe_2O_3	0.92	0.35	0.30	...	...
FeO	1.74	1.66	...	...	...
MgO	1.53	0.26	...	...	...
CaO	2.92	3.03	0.75	0.79	...
Na_2O	3.37	3.59	2.27	4.11	...
K_2O	5.04	4.07	12.96	9.74	16.9
H_2O-	0.34	0.40	0.44	0.29	...
H_2O+	0.43	0.39			
TiO_2	1.29	0.36	...	...	...
ZrO_2	none	0.01	...	...	...
P_2O_5	0.20	0.17	...	...	...
Cl	0.04	...	...	...	...
MnO	0.46	0.12	...	...	...
Remainder	...	1.81	...	...	...
	100.03	99.65	99.50	100.37	100.00

1. Quartz monzonite porphyry, Clover Mountain, Colo. R. M. Butters, analyst.

2. Quartz monzonite porphyry, Browns Gulch, Breckenridge district, Colo. R. C. Wells, analyst. Ransome, F. R., Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 45.

3. Pink orthoclase extracted from No. 1. R. M. Butters, analyst.

4. Orthoclase from nevadite of Chalk Mountain, Leadville region, Colo. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 349. Bull. U. S. Geol. Survey No. 419, 1910, pp. 109, 257.

5. Theoretical composition of orthoclase.

An analysis, by Mr. Butters, of the pink orthoclase from the quartz monzonite porphyry is shown in column 3 of the table above. The sample was carefully selected under a strong lens, by the writer, after crushing and bolting selected fragments of the phenocrysts. The contrast in color between the pink orthoclase and white plagioclase permitted the selection of pink homogeneous feldspar with no plagioclase. Every doubtful grain was discarded. The chemical analysis was made with extreme care. The result shows that the molecular ratio of Na_2O to K_2O is nearly .27, while the ratio of CaO to K_2O is about .094.

Column 4 shows the composition of a feldspar crystal from the nevadite of Chalk Mountain, Colorado, which contains .83 per cent lime, 3.97 per cent soda, and 4.53 per cent potash.[1] By comparison of the analyses it is seen that the amount of soda and lime in the feldspar of the Etna porphyry is much less than that

[1] See p. 154, this bulletin.

in the feldspar of the nevadite in proportion to the relative amounts of these oxides in the containing rocks. This difference may have been caused by the early crystallization of the plagioclase in the Etna porphyry, which left the residual solution relatively poor in lime and soda and rich in potash.

The following is the norm of the Etna porphyry according to the quantitative system:

Norm of Etna porphyry of Clover Mountain

Quartz	20.10
Orthoclase	29.47
Albite	28.30
Anorthite	11.12
Diopside	2.24
Hypersthene	3.86
Magnetite	1.39
Ilmenite	2.43
Apatite	0.31
	99.22

This norm corresponds to toscanose.

Below is the mineral composition of the Etna porphyry, as calculated from the chemical analysis. The orthoclase, as given in the table, contains the same proportions of soda and lime as the chemical analysis shows.

Mineral composition of Etna porphyry of Clover Mountain

Quartz	21.84
Orthoclase	32.42
Plagioclase (average $Ab_{14}An_5$)	30.35
Biotite	7.95
Hornblende	3.60
Magnetite	0.70
Ilmenite	0.76
Titanite	1.37
Apatite	0.31
	99.30

This rock corresponds very closely, in mineral composition, to Brögger's quartz monzonites, having approximately equal amounts of orthoclase and plagioclase.

OTHER VARIETIES OF QUARTZ MONZONITE PORPHYRY

Porphyries of a few small areas mapped as quartz monzonite porphyry do not conform to the type described.

The dike-like stock near the head of Tomichi Creek is partly composed of porphyry that does not differ essentially from the Etna type. Most of the body, however, is made up of a variety which was probably intruded independently and differs from the Etna type chiefly in that the groundmass forms a much greater proportion of the rock, and the phenocrysts are smaller, while orthoclase and quartz phenocrysts are few in number.

The small occurrence on the north slope of Contact Hill and the one just north of Bonanza Creek are probably parts of a single intrusion which is mostly covered by slope-wash and alluvium. This rock carries numerous large quartz phenocrysts and a few badly weathered feldspars in a dense, greenish-gray groundmass. No thin section of the rock was made.

The small area mapped as quartz monzonite porphyry a mile and a half northwest of Shavano Mountain contains two varieties which could not be readily separated in the mapping. One carries numerous bluish plagioclase phenocrysts three to five millimeters in diameter, and a few biotite crystals, in a rather coarse microgranitic groundmass of quartz and orthoclase. The second variety, which is essentially a granite porphyry, carries a few very small phenocrysts of biotite and acid plagioclase in a micrographitic groundmass composed chiefly of quartz and orthoclase, with a few titanite crystals.

ROCKS OF THE CHONOLITHS

ANDESITE

Occurrence.—Andesite is exposed throughout an area more than a mile in average width and about four miles in length, extending from Browns Gulch southwest nearly to the divide between the North and Middle forks. On the northwest side the contact between the andesite and underlying quartz monzonite dips southeastward 40° to 45°. On the southeast the andesite-gneiss contact is about vertical. At least the upper part of the andesite mass, therefore, is wedge-shaped, growing narrower downward. It is probable that the andesite was injected as a chonolith under a comparatively thin cover. This is suggested by the texture of the rock, while the relation of the andesite to the surrounding rocks all but precludes its having been extruded at the surface.

The tongue of rock extending from the andesite area westward between the quartz monzonite and quartz latite porphyry is slightly coarser in texture than the andesite proper and carries considerable quartz as phenocrysts or inclusions. The rock is too badly weathered to be named exactly but it is probably a dacite. Whether this rock is a phase of the andesite or was intruded independently, is not clear. There has been much brecciation in this zone, and fragments of both the andesite and the dacitic rock are cemented by a finer andesitic matrix.

Age relations.—The andesite is younger than the quartz monzonite gneiss, of which it incloses large xenoliths on the south and west slopes of Calico Mountain. It is probably much younger than the youngest plutonic rock of the region, but of this there is no proof. A mile and a quarter northwest of Mount Etna, boulders of breccia show many fragments of both andesite and the dacitic rock in a matrix of quartz latite porphyry. From this it is inferred that the andesite is older than the quartz latite porphyry.

Description.—The freshest rock is dark gray and has a dense groundmass which is far greater in volume than the phenocrysts. Many small phenocrysts of feldspar and of biotite, having a maximum diameter of three millimeters, are present. Pyrite grains are not uncommon in joint planes. The feldspars are commonly light greenish-gray, owing to the presence of minute grains of epidote. Cleavage faces of those which retain a glassy luster show albite twin striations under a lens.

In many exposures the rock is green because of the presence of abundant epidote. In several places the surfaces of blocks are covered by brown or red iron oxide. Calico Mountain presumably has taken its name from the variegated colors which this rock shows on its slopes. Wherever the andesite is exposed on slopes it is broken into sharply angular fragments a few inches in diameter.

Under the microscope hornblende appears as a phenocrystic mineral, in addition to plagioclase and biotite. No orthoclase phenocrysts are seen, in thin sections, but the chemical analysis indicates the presence of some orthoclase in the groundmass.

Plagioclase phenocrysts which combine albite and Carlsbad twinning are shown by the Michel-Lévy method to be labradorite having the composition of about Ab_2An_3. They exhibit only slight zonal banding and are hence apparently fairly uniform in composition.

The *biotite* is the ordinary brown, pleochroic variety. Many crystals show hexagonal outline. A "reaction rim" is common;

this seems to be composed mainly of black iron ore and kaolin. Under a high-power objective a sagenite web of rutile needles can be seen in many of the slightly altered biotite crystals. Pale-green *hornblende* is quite plentiful as a phenocryst. It shows alteration to a colorless amphibole, epidote, and iron ore.

The pilotaxitic groundmass contains closely packed, lath-shaped feldspar microlites, minute grains of iron ore, small prismatic crystals of apatite, a few prismatic zircon crystals, and secondary epidote, in addition to a considerable quantity of transparent, colorless material which is probably made up of quartz and orthoclase. The feldspar microlites are commonly once twinned and many show inclined extinction. They are apparently chiefly andesine. The iron ore, which is abundant, is probably largely ilmenite, as suggested by the considerable quantity of titania in the rock. No titanite can be seen.

Chemical and mineral composition. — The following is an analysis of a fairly fresh specimen of the andesite from near the head of Jennings Gulch:

Analysis of andesite of Jennings Gulch

[R. M. Butters, Analyst]

SiO_2	57.51	H_2O-	0.09
Al_2O_3	19.18	H_2O+	0.09
Fe_2O_3	1.76	TiO_2	2.02
FeO	3.39	ZrO_2	none
MgO	2.44	P_2O_5	0.41
CaO	6.32	Cl	0.07
Na_2O	3.28	FeS_2	0.23
K_2O	3.18	MnO	none
			99.97

The following is the norm according to the quantitative system:

Norm of andesite of Jennings Gulch

Quartz	9.66
Orthoclase	18.90
Albite	27.77
Anorthite	28.08
Diopside	0.46
Hypersthene	7.35
Magnetite	2.55
Ilmenite	3.80
Pyrite	0.23
Apatite	0.93
	99.73

This norm corresponds to shoshonose.

The following table gives the actual mineral composition, as calculated from the chemical analysis:

Mineral composition of andesite of Jennings Gulch

Quartz	13.02
Orthoclase	12.79
Plagioclase (average Ab_{10} An_9)	53.10
Hornblende	4.40
Biotite	10.66
Magnetite	1.62
Ilmenite	3.04
Pyrite	0.23
Apatite	0.93
	99.79

The hornblende and biotite were assumed to have the same composition as the hornblende and biotite noted on page 137. In the calculation it was found that the rock analysis gives about .40 per cent too much magnesia and .72 per cent too little ferrous oxide for the assumed composition of the hornblende and biotite. This difference was adjusted between the two minerals.

QUARTZ LATITE PORPHYRY

Occurrence.—This rock is exposed over a considerable area near the head of Middle Fork and Chalk Creek and on the south slope of Monumental Mountain. In addition to the several disconnected masses shown on the map, there is an exposure of the same rock on the southwest slope of Mount Etna. Because of the great amount of sliderock here, the boundary of this occurrence could not be determined with even a fair degree of accuracy. It is probable that all these disconnected masses originally formed part of a single chonolith which was split into several smaller bodies by the later quartz monzonite porphyry intrusion. The quartz latite porphyry is locally called diorite porphyry, but the character of the groundmass and the ratio of groundmass to phenocrysts do not justify the local name.

Age relations. — Since the dacitic rock that separates the quartz latite porphyry from the Pomeroy quartz monzonite furnishes fragments to the overlying quartz latite porphyry, the last-named rock is clearly younger than the dacitic porphyry. What is evidently the same quartz latite porphyry is found cementing andesite fragments in a breccia a mile and a quarter northwest of Mount Etna; the quartz latite body is, therefore, almost certainly younger than the andesite. The coarse-textured quartz monzonite porphyry carries inclusions of the quartz latite porphyry and sends dikelets into the body of this rock on the south slope of Monumental Mountain; the quartz latite porphyry is hence older than the quartz monzonite porphyry.

Description.—The rock is bluish-gray and shows in the hand specimen many phenocrysts of white to bluish feldspar, a few pink feldspars, numerous biotite and hornblende crystals, and an occasional titanite crystal. The feldspars are mostly less than three millimeters in diameter. Although an occasional biotite crystal may have a diameter of three or four millimeters, most of the biotite and hornblende crystals have a diameter of less than one millimeter. The groundmass is approximately equal to the phenocrysts in volume.

In thin section *plagioclase* is seen to be the most abundant phenocrystic mineral. The common albite twinning is, in a few crystals, combined with pericline or Carlsbad twins. The plagioclase ranges from basic andesine to oligoclase. Many crystals show a core of andesine surrounded by a shell of oligoclase. In phenocrysts of this character the oligoclase appears to be in excess of the andesine. A few *orthoclase* crystals are present in some specimens. Although the feldspars are in part automorphic many of the crystals have been broken, some have no regular outline, and a few have been embayed by re-solution. The feldspars inclose portions of the groundmass, small crystals of apatite and many minute needles which appear brown in transmitted light and may be rutile.

As a rule, *biotite* exceeds the hornblende in amount, but in some specimens these two minerals are present in nearly equal quantity. The biotite is the common brown variety. Many crystals are bent showing that there had been some movement of the magma after the mica had crystallized. The biotite shows more or less resorption in that some crystals are bordered by a very narrow band of magnetite powder. Other crystals are wholly unaltered.

The *hornblende* is the ordinary variety with an extinction angle of about 20°. Many hornblende crystals show no alteration; some show a resorption rim of magnetite dust; others have been completely replaced by a mixture of secondary material which contains considerable iron ore.

Quartz is very seldom seen as a phenocryst in the average rock. Where it does appear it has no crystal outline but is rounded and embayed by re-solution.

In addition to the minerals mentioned, titanite is shown by the microscope to be a plentiful accessory. A few prisms of zircon and many formless grains of iron ore are seen. The iron ore was probably, in large part, derived from the biotite and hornblende.

The most characteristic type of groundmass, as seen under a low-power objective, consists mainly of a microgranular aggregate of a doubly refracting mineral filled with a swarm of dust-like inclusions. With the aid of the highest power, minute crystals of zircon and apatite, besides glass and liquid inclusions, may be recognized. But there are still a greater number of indeterminable inclusions, among which are brown prismatic forms, brown to black octahedrons, and numerous dark, formless grains. The imperfectly defined grains which carry the minute inclusions are probably in large part orthoclase, although some are unquestionably quartz. There is no suggestion of lath-like feldspar microlites so commonly seen in andesites.

The type described may give way, on the one hand, to a variety slightly coarser, in which most of the grains are more certainly orthoclase. On the other hand, the groundmass becomes more finely granular, without the poikilitic effect and with abundant interstitial material which does not react on polarized light and is probably glass. All these varieties may be seen in one slide and in specimens from widely separated localities.

Beside these peculiarities of groundmass, the microscope shows small patches of porphyry of the same general composition as the surrounding rock but more coarsely crystalline. In one slide unstriated feldspar and much pyroxene make up most of an included fragment. This may be a crystallized fragment of impure magnesian limestone which had been fused by the heat of the magma. A study of the characters mentioned leaves the impression that there was considerable kneading of the magma after crystallization was well advanced, or rather, that successive pulsations forced the more mobile magma from below up into the cooler and better crystallized crust of which fragments were held by the invading magma when it came to rest. There is evidence of at least three not widely separated periods of crystallizing of the groundmass. The almost complete absence of flow-structure, the bent micas, and the ruptured feldspars lend support to this hypothesis.

Chemical and mineral composition. — The table shows the chemical composition of a specimen of quartz latite porphyry from the Mohammed tunnel. For comparison, the analysis of a quartz latite from near Silverton, Colorado,[1] is also given.

Analyses of quartz latite porphyries

	1	2		1	2
SiO_2	64.56	64.93	H_2O-	0.41	1.12
Al_2O_3	17.36	16.79	H_2O+	0.45	1.65
Fe_2O_3	0.76	3.54	TiO_2	0.61	0.53
FeO	1.81	0.32	ZrO_2	trace	0.03
MgO	0.73	0.65	P_2O_5	0.08	0.17
CaO	3.25	2.11	Cl	0.01	...
Na_2O	3.56	3.33	MnO	0.33	trace
K_2O	5.94	4.76	BaO	not det.	0.15
				99.86	100.08

1. Quartz latite porphyry from Mohammed tunnel, Monarch district. R. M. Butters, analyst.

2. Quartz latite from bench south of Greenhalgh Mountain, Silverton quadrangle. W. F. Hillebrand, analyst. Folio U. S. Geol. Survey No. 120, p. 10.

The following is the norm of the Monarch rock, calculated from the chemical analysis:

Norm of quartz latite porphyry from Mohammed tunnel

Quartz	12.96
Orthoclase	35.03
Albite	29.87
Anorthite	14.18
Diopside	0.92
Hypersthene	3.45
Magnetite	1.16
Ilmenite	1.22
Apatite	0.31
Water not used in calculation	0.86
	99.96

In the quantitative system the rock is toscanose.

Below is the actual mineral composition, or mode, calculated from the chemical analysis. The composition of the biotite and hornblende was assumed to be the same as that of the biotite and hornblende noted on page 137:

[1] Silverton Folio (No. 120), U. S. Geol. Survey, 1905, p. 10.

Mineral composition of quartz latite porphyry from Mohammed tunnel

Quartz	14.58
Orthoclase	31.14
Plagioclase (average Ab_5An_2)	42.66
Biotite	7.28
Hornblende	1.93
Magnetite	0.46
Titanite	0.98
Apatite	0.31
	99.34

The calculation of the mineral composition showed that the assumed chemical composition of the biotite and hornblende required .40 per cent more magnesia and .72 per cent less ferrous oxide than the rock analysis contains. An estimate of the relative amounts of component minerals from a thin section of the specimen analyzed would not differ greatly from the proportions as given in the table above. This section, however, contains much more biotite in proportion to hornblende than most of the slides examined.

DIKE-ROCKS

The quartz monzonite porphyry which occurs in one exceptionally strong dike has been described. Mention has also been made of the granite dikes which are apophyses of the quartz monzonite body.

Aside from the dikes mentioned, dikes of porphyry and felsite are common, especially near the borders of the Princeton quartz monzonite. They ordinarily range from a few inches to fifty feet in width. Most of them are less than thirty feet wide. Many are very irregular in their course in the sedimentary rocks, and some follow the bedding planes for considerable distances as intrusive sheets. As a rule, outcrops are easily followed on the ridges and higher parts of the slopes, but in the valleys talus and soil cover the dikes too deeply to permit them to be readily traced. There is little or no doubt that many of the dikes seen on the ridges and higher slopes are continuous through the valleys.

The dikes here described are found cutting the quartz monzonite gneiss, quartz monzonite, and Etna porphyry, besides the pre-Cambrian and Paleozoic rocks; but the relative age of the different kinds of dikes is unknown.

Like the granular intrusives, these dike-rocks are intermediate to acid in composition. Texturally they include these extremes: (1) very coarse porphyry almost phanerocrystalline, (2) pitchstone porphyry and felsite. Most of them, however, have intermediate porphyritic texture.

In the field it was found practically impossible to map separately all the varieties because of the numerous gradations and generally weathered condition of the rocks. Furthermore, many of the felsitic rocks, even if quite fresh, cannot, without chemical analyses, be accurately placed in a strict petrographic classification. For these reasons some dikes that are probably rhyolitic and a few that may be andesitic, are shown on the map in the same color as the latite and latite porphyry.

The study of thin sections shows that the dike-rocks include the following types: (1) monzonite porphyry, (2) quartz monzonite porphyry, (3) quartz latite porphyry almost identical in composition with the quartz latite porphyry of the chonolith, (4) latite porphyry which differs from the monzonite porphyry only by having a finer texture, (5) latite with few or no phenocrysts, (6) andesite porphyry, (7) rhyolite and rhyolite porphyry, and (8) pitchstone porphyry.

The typical quartz latite porphyry is found in only a few dikes. One of these is on the divide northeast of the head of Jennings Gulch; another is crossed by the road about half a mile west of the Victor mine in the Tomichi district. Examples of latite porphyry are most common east of the Continental Divide; because of the close resemblance of this rock to the monzonite porphyry described below it needs no further mention. Excepting the latite porphyry and quartz latite porphyry, the types mentioned are briefly described in the following paragraphs.

MONZONITE PORPHYRY

A large number of the dikes are formed of bluish-gray monzonite porphyry which carries, besides orthoclase and plagioclase, abundant hornblende, no biotite, and very little or no quartz. A few dikes have biotite instead of hornblende; others have both biotite and hornblende. Locally, cubes or grains of pyrite are abundant. In composition the dikes range from dioritic to syenitic, but perhaps a majority of them are typical monzonite porphyry, having orthoclase and plagioclase in nearly equal amount. Flow-structure is shown in several dikes by the parallel orientation of the hornblende crystals.

As a phenocryst, alkali feldspar, chiefly orthoclase, varies greatly in amount. In places it is practically absent. In other places it may equal the phenocrystic plagioclase in volume, but it is commonly subordinate to the plagioclase. Occasionally a small quartz phenocryst may be seen.

The groundmass is microcrystalline. In volume it may exceed the phenocrysts in varieties of porphyry with fairly large phenocrysts. From this maximum the groundmass decreases to only a few per cent of the rock mass in varieties with phenocrysts one to three millimeters in diameter. Good examples of porphyry composed almost entirely of phenocrysts may be seen in the dike southwest of Maysville, and near the top of Clover Mountain at the north edge of the dike. On Clover Mountain this rock appears to grade from the sides of the dike into the coarser quartz monzonite porphyry.

On Clover Mountain and in other places epidote is abundant, replacing the plagioclase in part and giving a greenish color to the rock.

The microscope shows, in addition to the megascopic constituents, apatite, zircon, iron ore, and probably allanite. Apatite and zircon are very rare and in minute crystals. Iron ore is plentiful in minute anhedrons and octahedrons. Titanite is much less common than it is in the quartz monzonite porphyry and the quartz monzonite. In a few slides small formless grains of a brown, strongly pleochroic mineral with high refractive indices, are seen. Since the absorption of the slow ray is greatest, producing a deep brown, it is inferred that this mineral is allanite.

The hornblende is greenish-brown and has an extinction angle of about 15°. This mineral is automorphic and many of the crystals are twinned. In one slide the hornblendes have a resorption border showing two zones. The first zone next to the hornblende is composed mainly of black iron ore. The outer and wider zone is too finely crystallized and too much altered to permit certain determination. It is probably in part pyroxene, but much of the material has a low refractive index and shows pleochroism and interference colors which suggest biotite. In many specimens alteration of the hornblende has given rise to epidote and chlorite with iron ore. The biotite is the common brown variety. It shows alterations to epidote and chlorite with iron ore.

The plagioclase occurs in well-formed crystals. Albite twinning is common, in some instances combined with Carlsbad twins. Zonal structure is pronounced in most of the crystals. The most basic feldspar at the center is andesine; the outer zone is oligoclase or alkali feldspar. Epidote and sericite are very common alteration products. Zoisite accompanies the epidote in a few specimens. Although some calcite has been formed, it is not abundant. Most of the orthoclase phenocrysts, aside from the numerous inclusions of plagioclase, are homogeneous, but a few carry a small amount of microperthitically intergrown plagioclase. One peculiar phenocryst has a core of alkalic feldspar poikilitically inclosing small plagioclase crystals and quartz grains. Surrounding this core is a wide zone with fewer inclusions but intergrown micrographically with quartz. The feldspar of both zones is partly unstriated, but partly very finely twinned after the albite and pericline laws. This feldspar probably carries a high soda content. The rock itself marks a transition to the quartz monzonite porphyry. Where quartz appears as a phenocryst it has been corroded as in the more quartzose porphyry.

The groundmass is, in general, a microgranular aggregate of orthoclase and plagioclase with considerable iron ore. Shreds of hornblende and biotite are not uncommon and in some specimens a little interstitial quartz appears. Rarely the groundmass of the more micaceous rock is micropoikilitic, being composed essentially of orthoclase grains inclosing great numbers of small brick-shaped plagioclases. A little interstitial quartz is present in this variety. Still more rare is the groundmass composed essentially of orthoclase with a small amount of micrographically intergrown quartz. The ratio of orthoclase to plagioclase in the groundmass varies widely. In some specimens, even those in which the feldspar phenocrysts are practically all plagioclase, the groundmass is composed mainly of orthoclase. In others plagioclase is dominant.

QUARTZ MONZONITE PORPHYRY

Under this name are here included all the coarser porphyries composed essentially of orthoclase and plagioclase in nearly equal quantity, on the average, with more or less quartz. Biotite and hornblende are everywhere present. Quartz may vary from an almost negligible component of the groundmass to a very prominent phenocrystic mineral. The ratio of orthoclase to plagioclase is variable, but both of these feldspars are constantly present. Although the rock has an average composition about intermediate between a granite and a diorite, there are local granitic, syenitic and dioritic varieties. By decrease of quartz the quartz monzonite porphyry grades into monzonite porphyry. Except in having a finer texture, generally, and considerable variation in the quantity of quartz and dark minerals, the quartz monzonite porphyry of the smaller dikes does not differ materially from the Etna porphyry described.

LATITE

This rock is commonly very light gray or white in color and felsitic in texture. Some dikes carry no megascopic phenocrysts. The phenocrysts which occur in some dikes are very small. They are chiefly feldspar, but biotite or hornblende may be present in some places. Quartz appears sparingly in small phenocrysts in a few dikes and marks a transition to the rhyolite. Small cubes of pyrite are locally abundant. The rock is generally much weathered; the original ferromagnesian minerals, as a rule, have been completely replaced by alteration products.

The microscope shows in most specimens apatite, iron ore, biotite, plagioclase, and orthoclase. Titanite, hornblende, and quartz are present in some specimens. Fresh material is rarely found; the slides commonly carry a considerable quantity of secondary minerals, principally kaolin, sericite, epidote, chlorite, and calcite. Both orthoclase and acid plagioclase occur as phenocrysts, the relative proportions varying greatly.

Two types of groundmass are seen in the latite. The first is a micropoikilitic type in which small grains of orthoclase and perhaps quartz, inclose numerous lath-shaped plagioclase microlites. The second and more common type of groundmass consists of a microgranular aggregate of orthoclase and plagioclase besides a little quartz in some specimens.

ANDESITE PORPHYRY

A few dikes of andesite porphyry occur on both sides of the Continental Divide. One of the most typical is just east of Boss Lake. Another is on the north slope of Contact Hill in the Tomichi district. This rock is greenish-gray and shows numerous small crystals of feldspar and hornblende with a few flakes of biotite.

In thin section are seen apatite, iron ore, hornblende, biotite, plagioclase, and a little orthoclase. Apatite has its ordinary habit. For an accessory black iron ore is quite abundant in octahedrons and formless grains.

The hornblende is greenish-brown and has an extinction angle of about 15°. The biotite is the ordinary brown variety. Plagioclase is abundant in automorphic tabular crystals many of which combine Carlsbad and albite twinning. Extinction angles indicate that the plagioclase is mainly andesine, but most of the crystals are bordered by a narrow zone of a more acid variety.

The groundmass is composed of lath-like plagioclase crystals, a small quantity of interstitial orthoclase, and small shreds of biotite and hornblende.

RHYOLITE

The rhyolite presents two types: (1) felsitic rock with few and small phenocrysts, (2) rhyolite porphyry in which phenocrysts of quartz and feldspar are common.

The best examples of the first type are found on the east slope of Taylor Mountain. The rock is ordinarily light gray or almost white; in some places it is stained by brown oxide of iron or dendrites of black oxide of manganese. In color and texture this rock resembles the "white porphyry" of the Leadville[1] district. Some dikes have a few feldspar phenocrysts one to three millimeters in diameter. Small quartz phenocrysts are sometimes present, but in general the quartz is confined to the groundmass. Minute biotite crystals or pseudomorphs after biotite are sparingly present. Pyrite cubes or limonite pseudomorphs after pyrite are not uncommon.

In some thin sections both orthoclase and plagioclase are present as phenocrysts. In others, plagioclase is the only phenocrystic feldspar. Many of the phenocrysts are much sericitized and kaolinized and are difficult of specific determination. Extinction angles indicate that the plagioclase is at least in part andesine. The biotite is the common brown variety, but in most specimens it has been replaced by epidote, chlorite, and iron ore.

The groundmass is generally micrograntic, composed chiefly of unstriated feldspar and quartz. A few specimens carry a considerable residue of micrographically intergrown quartz and feldspar. In one thin section the quartz and the feldspar of the

[1] Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 76, 324.

groundmass swarm with dust-like inclusions. Several specimens have a micropoikilitic groundmass composed essentially of orthoclase inclosing minute lath-shaped microlites of plagioclase with very low extinction angles. In this variety the quantity of quartz is very small and the rhyolite approaches latite in composition.

Accessory minerals are apatite, titanite, and zircon. A few small apatite crystals are found in all the slides examined. Titanite is seen only occasionally. Small, stout zircon crystals are numerous in some specimens, but are not present in others.

RHYOLITE PORPHYRY

Rhyolite porphyry is found in typical development in a dike in and near the fault in the vicinity of the Spar Copper mine. The same rock occurs in a sheet above the coarse quartzite east of the David H. mine and in a dike or sheet near the head of the gulch southeast of Lake Hill. It is probable that these three exposures are parts of a single intrusion which may not reach the surface continuously or which, having once been exposed, may now be covered by talus through part of its course.

As seen at the surface, the rhyolite porphyry is light gray or nearly white, and carries many quartz phenocrysts and a few feldspar crystals two to eight millimeters in diameter, in a microcrystalline groundmass. Fresher material from the dike cut in the Parole tunnel is dark gray in color and carries, in addition to quartz and feldspar, small phenocrysts of biotite.

Examined in thin section the quartz phenocrysts show good bipyramidal outline and practically no resorption phenomena. Large fluid inclusions are common; a few crystals also inclose portions of groundmass.

Orthoclase and plagioclase, as phenocrysts, are nearly equal in amount. Measurement of extinction angles of crystals which combine Carlsbad twinning with the common albite twinning, shows that the plagioclase is mainly andesine. In one slide, however, labradorite with the composition of about Ab_2An_3 was noted. The biotite of the rock at the surface is replaced by epidote and chlorite.

The groundmass is chiefly a microgranular aggregate of orthoclase and quartz, although in several specimens the orthoclase incloses micropoikilitically small lath-shaped plagioclase microlites. Most of these microlites have parallel extinction, while a number show an extinction angle of a few degrees. The feldspar of the groundmass is considerably kaolinized.

This rock tends to be monzonitic in character, but the phenocrystic feldspar, although nearly half plagioclase, is very much less than the feldspar of the groundmass, which is apparently largely orthoclase. This preponderance of orthoclase and the high quartz content make the rock more granitic than monzonitic in mineral composition.

A variety of rhyolite porphyry which marks a transition, in both texture and composition, toward the quartz monzonite porphyry is found in a dike at the north end of Hoffman Park. This variety has large pink orthoclase phenocrysts and many andesine phenocrysts, besides quartz and biotite in a microgranitic groundmass of quartz and orthoclase. The phenocrysts equal or exceed the groundmass in volume. Accessory apatite and titanite are present.

PITCHSTONE PORPHYRY

A border of pitchstone porphyry about two feet thick was observed on the west side of a rhyolite porphyry dike exposed in the Morning Star mine. The east side of the dike was not uncovered when the mine was visited. The main part of the dike is rhyolite porphyry with holocrystalline groundmass.

A short distance southwest of the Morning Star mine a similar dike was cut by a prospect tunnel driven by Mr. W. T. McConnell. This dike is about twenty feet wide and dips northward 60°. A few inches of brown pitchstone porphyry is found on the upper border. The remainder of the dike is rhyolite porphyry, much decomposed, but similar in composition and texture to that in the Morning Star.

A number of shallow prospect holes reached pitchstone porphyry, as shown by the dumps, along a line about half a mile in length, extending northward from near the Breadwinner shaft, southeast of North Star. Nowhere along this line is the pitchstone now seen in place but the fact that the dump at one fairly deep shaft shows both pitchstone porphyry and rhyolite porphyry like the varieties in the Morning Star mine and McConnell's tunnel, suggests the probability that the relation between the two varieties is the same here as in the dikes observed. The dike, or sheet, may be inclined from the vertical at a high angle. If this supposition is correct the shallow holes from which only a small amount of pitchstone was removed, did not reach the better crystallized interior.

Description.—The pitchstone porphyry is commonly green, though the brown variety with resinous luster occurs in the dike cut by McConnell's tunnel. Feldspar phenocrysts one to five millimeters in diameter are common, and a few very small biotite crystals can be seen with the aid of a lens. However, the groundmass far exceeds the phenocrysts in volume.

In addition to the minerals mentioned, quartz is occasionally seen in thin section as a phenocryst. The quartz offers no evidence of resorption, but shows well-developed prisms and rhombohedrons. Orthoclase and plagioclase, as phenocrysts, are present in about equal amount. As determined by measurements on crystals which combine both Carlsbad and albite twinning, the plagioclase is andesine having the composition of about Ab_1An_1. Ordinary brown biotite is present in small flakes and plates with hexagonal outline.

Accessory components are apatite, zircon, titanite, and magnetite. Apatite is plentiful in needle-like crystals both in the groundmass and as inclusions in the feldspars. Zircon is far less common and seen in small stout crystals only in the groundmass. A few automorphic crystals of titanite are present. Magnetite occurs in small quantity in rounded grains.

The groundmass is composed mainly of glass in which are many minute elongated forms of incipient crystallization, which react feebly on polarized light. In this rock there do not seem to be present any peculiar crystallites, such as have been observed in pitchstone of other localities.

EXTRUSIVE ROCKS

VOLCANIC BRECCIA

Volcanic breccia forms the top of the Sawatch Range in the vicinity of what we have called Vulcan Mountain. It extends down the east slope less than a quarter of a mile, but reaches down nearly half a mile on the west side. Only the largest areas are shown on the map. Smaller exposures are found on the south shoulder of Central Mountain and along Fort Scott Gulch.

Age relations.—The breccia carries fragments of nearly every other rock in this vicinity, indicating that it is one of the latest products of igneous activity. It does not appear to have broken through the quartz monzonite porphyry nor does this porphyry inclose fragments of the breccia. Since the breccia and the coarse porphyry are not found in contact with each other there is no observed field evidence of the relative age of the two. However, the character of the breccia shows that it is an extrusive rock, and there is no evidence that a great amount of material has been removed from above it by erosion. On the other hand, the coarse crystallization of the quartz monzonite porphyry now exposed at the surface, indicates that erosion has removed a much greater covering from above it than from above the breccia. From these considerations it appears probable that the volcanic breccia is the youngest igneous rock in the district, excepting possibly the flow breccia and some of the dikes.

Description.—The breccia generally has a dense, greenish-gray matrix cementing angular fragments among which can be identified pre-Cambrian granite, quartzite, arkose, chert, limestone, marble, baked shale, and quartz monzonite gneiss. The relative quantities of included rocks vary in different places, but fragments of sediments are probably the most abundant. The inclusions are numerous and in sharp contrast with the matrix, readily catching the eye. The greater number of the most conspicuous fragments range from a quarter of an inch to two inches across (about 0.5 cm. to 5 cm.). They run down, however, on the one hand, to microscopic in size, and on the other hand, not infrequently reach several feet in diameter. Near the border of the breccia area, masses of rock 100 feet or more in diameter are found.

In thin section the matrix is seen to be largely glass of which the clastic character is shown, in places, by shreds and angular fragments with outlines like those seen in volcanic ash. Minute microlites of what is probably feldspar or feldspar and quartz, can be seen sparingly distributed through the glass. Occasional small crystals of zircon and of titanite are present. Broken and comminuted grains of quartz and orthoclase, and a little plagioclase, are common. The matrix is much altered and contains considerable kaolin, epidote, chlorite, and calcite. Without an analysis it is impossible to place this rock accurately, but it is probably a rhyolite with a low or moderate silica content.

FLOW BRECCIA

Brittle Silver Mountain near the north boundary of the Tomichi district, is capped by a flow breccia which is probably one of the youngest igneous rocks of the region.

This breccia, which is brownish-gray, contains numerous angular fragments of feldspar and dark gray-brown porphyry, besides a few quartz fragments, in a light-gray matrix. The porphyry fragments range from an inch or more in diameter down to microscopic dimensions. Some of these are equidimensional, but a great many are more or less lenticular in form, with their longest axes parallel to the direction of rock-flow.

Under a low power of the microscope the flow-structure is conspicuous. The matrix is composed almost entirely of glass, with here and there a minute speck of anisotropic material.

The included porphyry fragments are much weathered, but do not closely resemble any rock found in the district in mass. The phenocrysts, which form a small fraction of the volume of the fragments, are chiefly orthoclase, with a few plagioclase and biotite crystals. The biotite is almost completely replaced by chlorite, epidote, and black iron ore. The groundmass is principally glass with a few minute grains of quartz, or quartz and feldspar.

No analysis of the breccia has been made, but it is inferred from the microscopic study that the composition is essentially that of a rhyolite, having perhaps a rather low silica content.

CHAPTER IX

GENERAL PETROLOGY OF THE POST-CARBONIFEROUS IGNEOUS ROCKS

SUMMARY OF POST-CARBONIFEROUS IGNEOUS HISTORY

It has been shown in the preceding chapter that nearly all the rocks here considered are younger than the youngest Paleozoic sediments, and reasons have been given, in Chapter V, for believing they are of post-Cretaceous age.

SUCCESSION OF INTRUSIONS

With but few exceptions, the relative age of the successive intrusions is determinable from field relations which were specifically mentioned under the several rock types in the chapter on petrography. The relative age of the Pomeroy quartz monzonite is in doubt, but this rock is probably older than the Princeton quartz monzonite and may be older than the quartz monzonite gneiss. There is no field evidence bearing on the age relations between the quartz diorite and quartz monzonite gneiss, but both are demonstrably older than the Princeton quartz monzonite. According to Brögger[1] and Harker[2], a series of plutonic intrusions normally begins with the most basic member and is followed by successive intrusions of increasing acidity. It is not improbable that this order was followed in the region here considered. The monzonitic diorite stock near Monarch may or may not have been intruded synchronously with the typical quartz diorite.

If we assume that the three dioritic stocks were intruded simultaneously and that the oldest three intrusions, whose relative age is in doubt, were intruded in the order of increasing acidity, the succession is:

1. Quartz diorite.
2. Pomeroy quartz monzonite.
3. Quartz monzonite gneiss.

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[1] Brögger, W. C., Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol, 1895, p. 175.

[2] Harker, Alfred, The natural history of igneous rocks, 1909, p. 116.

4. Princeton quartz monzonite.
5. Granite.
6. Andesite.
7. Quartz latite porphyry.
8. Etna quartz monzonite porphyry.
9. Various dike-rocks ranging from andesite to rhyolite in composition. Some of these may have been intruded synchronously with one or more of the larger porphyry bodies.
10. Volcanic breccia and flow breccia.

The igneous cycle.—Harker[1] considers that the normal cycle of igneous activity is characterized successively by three phases: (1) volcanic extrusions, (2) plutonic intrusions, and (3) minor intrusions. He, however, cites exceptions to this order and states that the normal cycle is sometimes followed by a relatively feeble extrusive phase.

In the Monarch and Tomichi districts the observed order is: (1) plutonic intrusions, (2) minor intrusions, (3) extrusion. Here the chonolithic intrusions, which Harker would evidently include with minor intrusions, were followed by the intrusion of Etna porphyry which forms a considerable stock. This has features in common with both plutonic and minor intrusions, and is here classed with the latter, principally because of its relative age. It is not impossible that the igneous history began with extrusive rather than intrusive activity, but, if so, the early effusive rocks have been removed by erosion.

PHYSICAL CONDITION OF THE INTRUSIVE MAGMAS

In the section on the forms of the intrusive bodies and in the chapter on petrography are noted some observations which have a bearing on the inferred physical character of the magma of the several intrusions. In this section these observations are summarized and inferences drawn concerning the relative viscosity of the magma of the successive most important intrusions in the supposed order of age. In writing the following paragraphs, the writer has made frequent use of the works of Harker,[2] Iddings,[3] Pirsson,[4] and others, and has merely made application of known principles and theories, without attempting anything original.

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[1] Harker, Alfred, op. cit., p. 25.

[2] Harker, Alfred, The natural history of igneous rocks, 1909.

[3] Iddings, J. P., On the crystallization of igneous rocks: Bull. Phil. Soc. of Washington, vol. 11, 1899, pp. 65-113.
Igneous rocks, vol. 1, 1909.

[4] Pirsson, L. V., On the phenocrysts of intrusive igneous rocks: Am. Jour. Science, 4th ser., vol. 7, 1889, pp. 271-280.

QUARTZ DIORITE

The quartz diorite magma had apparently, on the whole, a considerable degree of fluidity, as is common in a magma comparatively rich in the bases. That it was intruded between cold walls which chilled the magma rather rapidly is indicated by the porphyry facies near the contact.

POMEROY QUARTZ MONZONITE

The composition of this rock does not differ greatly from that of the Princeton quartz monzonite. The texture suggests a considerable degree of fluidity during the crystallization of plagioclase and ferromagnesian minerals. The eutectic intergrowth of quartz and orthoclase may indicate a low freezing-point and easy crystallization, although the mass seems to be a typical stock and specimens from the breast of the Pride of the West tunnel have a texture identical with that of specimens from the top of Grizzly Mountain. Hence it would seem that the geological conditions were favorable to slow cooling and crystallization at a high temperature. The porphyritic border facies indicates that the rock cooled rapidly in contact with the adjacent rock into which the quartz monzonite was intruded.

QUARTZ MONZONITE GNEISS

The coarse grain and extremely large feldspar crystals of the gneiss presuppose a high degree of molecular mobility in the magma at the time of crystallization. This was doubtless caused in large part by the high temperature of the magma but probably in greater degree by the presence of mineralizing agents.

The exact depth at which this magma crystallized is indeterminable from known facts. At the time of intrusion the Paleozoic sediments were at least a mile in thickness, probably 7,000 feet, and it is not unlikely that they were overlain by later deposits. Were the thickness of the sediments known, the problem would be complicated by the high dip of the strata, but there is no reason to believe the thickness of the cover was less than the stratigraphic thickness. Hence the depth at which the final stage of crystallization took place was at least one mile, and probably much more. Reasons for inferring that crystallization was far advanced before the magma came to rest were given in the previous chapter. But the probable great depth of crystallization and consequent slow cooling, are hardly sufficient to account for the evident low viscosity of the magma. In composition the gneiss does not differ greatly from many of the pre-Cambrian granites which were probably intruded at a depth at least as great as was the post-Carboniferous gneiss. Still, this gneiss is much coarser in texture than any Colorado granites, excepting pegmatite, that the writer has seen.

It would seem that the low viscosity of the magma must have been caused in large part by the presence of mineralizing gases, such as H_2O. Although a variety of mineralizing agents, such as gases containing boron and fluorine, may have been present, no boron or fluorine minerals were seen either in the gneiss itself or in the contact-metamorphic zone.

PRINCETON QUARTZ MONZONITE

Excepting the border facies of the quartz monzonite in the Chalk Creek district, this quartz monzonite has a practically uniform texture in the batholith and in the smaller stocks, and from the center to the inclosing walls. The grain, which is medium to coarse, indicates a considerable degree of fluidity of the magma.

This quartz monzonite was probably intruded under nearly the same thickness of cover as was the gneiss. The temperature of the inclosing rock was materially raised for a considerable distance from the intrusive rock, as shown by the wide contact-metamorphic zone. Hence the crystallization of the quartz monzonite took place under fairly uniform conditions of cooling even at the contact. The increase in temperature of the wall-rock was doubtless caused chiefly by the heat from the large bodies of magma which formed the massive quartz monzonite, but it is not improbable that at the time of this intrusion there still remained some heat effects of the previous gneiss intrusion.

Mineralizing agents doubtless had some part in maintaining the fluidity of the magma. Although the contact-metamorphic zone is apparently comparatively free from minerals which contain the common mineralizers except water, the presence of boron and probable flourine, in the magma is indicated by the tourmaline in the pegmatite vein at Boss Lake.

GRANITE

The granite may have been intruded under a thick cover soon after the quartz monzonite had crystallized and cooled, or it may have been intruded at a much later time after erosion had materially lowered the general surface of the region. The granite porphyry facies at the margin of the stock in Browns

Gulch points to a comparatively cold wall rock and consequent rapid cooling. That considerable fluidity was maintained almost throughout the process of crystallization in most of the body is shown by the coarse texture of the granite and by a coarsely crystallized quartz-feldspar vein, less than an inch thick, extending from the granite into the large inclusion of Pomeroy quartz monzonite. That the bulk of the rock crystallized after the granite magma came to rest is indicated by the marginal facies of granite porphyry which carries small automorphic quartz and feldspar phenocrysts in a micrographic to micrographic groundmass.

The original heat of the mass and that evolved during crystallization were doubtless important factors in preserving a low viscosity, but mineralizing agents common to granite magmas were probably also very effective. Among these mineralizers, gases containing fluorine and hydroxyl were present as evidenced by the minerals which have crystallized in the miarolitic cavities.

ANDESITE

The andesite magma was one of the least acid in the district, and would probably have crystallized with about the same texture as that of the quartz diorite under the same geologic conditions. The fabric points to a viscous magma. The geologic occurrence indicates that the viscosity was largely caused by rapid cooling, owing to a comparatively thin cover and small quantity of the intrusive rock.

QUARTZ LATITE PORPHYRY

The bent and broken condition of the phenocrysts of the quartz latite porphyry shows that they had formed before the magma came to rest. The incomplete crystallization of the groundmass points to a high viscosity. While this viscosity was doubtless influenced by a high proportion of alumina, potash, and silica, the most important factor was probably rapid cooling on account of the comparatively small body of magma and a thin cover.

ETNA PORPHYRY

The texture of this porphyry, excepting a narrow marginal, felsitic facies where the long dike cuts the granular intrusives, is uniformly much coarser than that commonly seen in aphanitic rocks. The felsitic border mentioned would indicate that the gneiss and the massive quartz monzonite had completely cooled prior to the intrusion of Etna porphyry, and also that the very large phenocrysts are not of intratelluric origin. Had the phenocrysts formed before the magma came to rest, they might reasonably be expected to be distributed in the rock close to the walls as well as at a distance.

The quartz monzonite porphyry magma, as a whole, must have had a low viscosity to permit the development of the very large phenocrysts and fairly coarse groundmass. It is not impossible that the porphyry now exposed crystallized in openings through which the magma reached the surface as a flow. Under these conditions continuous passage could warm the wall rock sufficiently to prevent rapid cooling of the magma after the movement had stopped.

Regardless of the part that may have been played by high temperature, mineralizing agents must be considered an important factor in maintaining the low viscosity. The growth of orthoclase crystals after a large proportion of the plagioclase had crystallized suggests the presence of catalytic agents that would offset in some degree the viscosity that a high proportion of quartz and orthoclase in solution would tend to cause. This growth may have been promoted by an increasing proportion of water in the residual mother-liquor, owing to the withdrawal from the solution of the oxides that entered into the crystallization of the older constituents.

RELATIONSHIPS OF THE PREDOMINANT ROCK TYPES

TEXTURAL RELATIONSHIPS

The general similarity of texture that has often been noted in various regions among closely related rock types originating from a common magma, is nearly absent from the rocks here considered. The table below shows the prevailing textural varieties of five of the intrusive rocks which have a similar chemical and mineral composition. The granite and the quartz diorite have a texture similar to that of the Princeton quartz monzonite.

Rock	*Texture*
Quartz monzonite gneiss	Extremely coarse, porphyritic gneissic.
Princeton quartz monzonite	Medium to coarse, even-granular.

Rock	*Texture*
Pomeroy quartz monzonite........	Hypautomorphic crystals of plagioclase and ferromagnesian minerals with much interstitial graphically intergrown quartz and orthoclase.
Etna quartz monzonite porphyry..	Large, conspicuous orthoclase phenocrysts, smaller plagioclase, hornblende, and biotite phenocrysts, subordinate microgranitic groundmass.
Quartz latite porphyry...........	Numerous small phenocrysts in predominant groundmass partly glass.

MINERAL RELATIONSHIPS

The similarity in mineral composition of the analyzed rocks is brought out in the following table:

Mineral composition of intrusive rocks of the Monarch district

	1	2	3	4	5	6	7	8
Quartz.............	13.7	17.5	22.9	18.8	30.4	13.0	14.6	21.8
Orthoclase and microcline............	18.9	28.6	31.6	25.8	33.9[5]	12.8[5]	31.1[5]	32.4
Plagioclase..........	39.8[1]	40.5[2]	36.1[3]	42.5[4]	31.6[6]	53.1[7]	42.7[8]	30.4[9]
Augite..............	6.0	little	.....	rare	.....	......	......	......
Hornblende.........	4.1	6.9	rare	2.9	.....	4.4	1.9	3.6
Biotite.............	15.0	4.0	6.5	8.2	2.9	10.7	7.3	8.0
Iron ore............	2.4	2.2	1.9	1.2	.2	4.9	.5	1.5
Titanite............	little	little	.6	.6	.8	......	1.0	1.4
Allanite.............	.....	.....	little	.....	.....	......	......	......
Apatite.............	little	little	.3	little	little	.9	.3	.3
Zircon..............	little	little	little	little	little	little	little	little

[1]Ab_5An_3 to Ab_1An_1
[2]Ab_1An_1
[3]Ab_8An_3
[4]Ab_4An_3 to Ab_2An_3
[5]Orthoclase molecule
[6]Albite molecule 29.34, anorthite molecule 2.22
[7]$Ab_{10}An_9$
[8]Ab_5An_2
[9]$Ab_{14}An_5$

1. Quartz diorite.
2. Pomeroy quartz monzonite.
3. Quartz monzonite gneiss.
4. Princeton quartz monzonite.
5. Granite.
6. Andesite.
7. Quartz latite porphyry.
8. Etna quartz monzonite porphyry.

Excepting the granite, all are closely related, and differ among themselves chiefly in the proportions of the essential components. The persistence of considerable quartz, orthoclase, and biotite throughout the series is noticeable. Hornblende and andesine are found in all except the granite, though hornblende is extremely rare in the gneiss. Titanite is a very common accessory, and present in considerable quantity. It was not seen in the few andesite slides examined, but its possible presence is suggested by the considerable titania content shown by the analysis. Augite and allanite are the only primary minerals noted that are not present in most of the rocks.

CHEMICAL RELATIONSHIPS

Although there was comparatively little differentiation in any one of the several bodies after it was intruded, there was much abyssal differentiation, that is, prior to the ascent of the magma. This resulted in splitting off such different magmas as those which formed the granite and quartz diorite, respectively. Since the Princeton quartz monzonite exceeds all the other intrusions many times, in areal extent and evidently in volume, it is very probable that it fairly closely represents the parent magma. A mixture of the granite, Pomeroy quartz monzonite, quartz diorite, and andesite in the proportions in which these rocks occur in the region might differ slightly in chemical composition from the Princeton quartz monzonite. Yet they form but a very small fraction of the whole volume of the intrusive rocks. If these rocks alone had separated from the parent magma, they could not have materially affected the composition of the remainder, which may be considered as the approximate equivalent of the Princeton quartz monzonite.

For comparison, the nine analyses of Monarch rocks recorded in the preceding chapter, with the molecular proportions of the essential oxides, are brought together in one table (p. 186). The general relationship of the several rocks is better shown in the accompanying variation diagram (Fig. 5). The molecular proportions of silica are plotted as abscissas, the molecular proportions of the other oxides as ordinates.

Analyses of rocks of the Monarch district, Elk Mountains, and West Elk Mountains

	1	2	3	4	5	6	7	8	9
SiO_2	57.39	57.51	57.67	62.60	64.56	66.71	67.64	67.90	74.27
	.957	.959	.961	1.043	1.076	1.112	1.127	1.132	1.238
Al_2O_3	18.26	19.18	18.07	18.16	17.36	15.04	14.75	16.08	13.67
	.179	.188	.177	.178	.171	.147	.145	.158	.134
Fe_2O_3	1.58	1.76	1.09	.91	.76	.92	.81	.83	.48
	.010	.011	.007	.006	.005	.006	.005	.005	.003
FeO	5.10	3.39	4.23	2.72	1.81	1.74	1.95	2.02	.45
	.071	.047	.059	.038	.025	.024	.027	.028	.006
MgO	1.51	2.44	2.69	.96	.73	1.53	.94	.73	.12
	.038	.061	.067	.024	.018	.038	.024	.018	.003
CaO	6.52	6.32	6.24	5.30	3.25	2.92	3.98	2.86	.65
	.116	.113	.112	.095	.058	.052	.071	.051	.012
Na_2O	2.78	3.28	3.14	3.02	3.56	3.37	3.40	4.08	3.48
	.045	.053	.051	.048	.057	.054	.055	.066	.056
K_2O	4.59	3.18	4.02	4.10	5.94	5.04	4.06	4.11	5.90
	.049	.034	.043	.044	.063	.053	.044	.044	.063
H_2O-[1]	.20	.09	.22	.28	.41	.34	.13	.14	.10
H_2O+[2]	.11	.09	.17	.34	.45	.43	.19	.21	.04
TiO_2	1.11	2.02	1.04	1.02	.61	1.29	1.36	1.15	.49
	.014	.025	.013	.013	.008	.016	.017	.014	.006
ZrO_2	.03	None	.32	trace	trace	none	trace	trace	.01
P_2O_5	.11	.41	.11	.06	.08	.20	.20	.12	.04
Cl	.05	.07	.04	.04	.01	.04	.08	.01	.02
MnO	.88	none	.80	.50	.33	.46	.27	none	none
	.013	......	.011	.007	.004	.006	.004	......	......
FeS_2	......	.23	......	......	......	......	......	......	......
Remainder	......	......	......	......	......	......	......	......	......
	100.22	99.97	99.85	100.01	99.86	100.03	99.76	100.24	99.72

	10	11	12	13	14	15	16	17
SiO_2	61.42	62.71	62.85	63.05	65.36	65.71	71.56	74.84
	1.024	1.045	1.048	1.051	1.089	1.095	1.193	1.247
Al_2O_3	17.69	17.06	16.21	15.58	15.48	18.30	14.91	14.05
	.174	.168	.159	.153	.152	.179	.146	.138
Fe_2O_3	4.24	3.79	3.08	2.92	3.09	1.19	1.47	.17
	.026	.024	.019	.018	.019	.008	.009	.001
FeO	1.74	2.74	1.46	2.11	1.21	1.53	1.04	.31
	.024	.038	.020	.029	.017	.021	.014	.004
MgO	1.81	1.78	1.47	1.70	1.53	.98	.08	trace
	.045	.045	.037	.043	.038	.025	.002	......
CaO	5.29	5.51	4.72	4.15	4.14	2.17	1.98	1.57
	.095	.098	.084	.074	.074	.039	.036	.028
Na_2O	3.19	3.54	3.49	3.77	3.58	5.00	3.78	3.66
	.051	.057	.056	.061	.058	.081	.061	.059
K_2O	3.14	2.96	3.10	3.66	3.41	3.95	4.94	3.14
	.033	.032	.033	.039	.036	.042	.052	.033
H_2O-[1]	.97	.24	.29[3]	.55[3]	.82[3]	1.39	.44	2.33
H_2O+[2]			2.03[4]	1.38[4]	.70[4]			
TiO_2	.37	......	.41	.60	.52	und.	......	......
	.005	......	.005	.008	.006	......	......	......
ZrO_2	......	......	......	......	......	......	......	......
P_2O_5	.14	none	.48	.27	.25	......	trace	......
Cl	......	......	......	......	......	......	......	......
MnO	.19	trace	.15	.12	.19	.02	......	......
	.003	......	.002	.002	.003	......	......	......
FeS_2	......	......	......	......	......	......	......	......
Remainder	.09	......	.11	.20	.08	......	......	......
	100.28	100.33	99.85	100.06	100.36	100.24	100.20	100.07

[1]At 110° [2]Above 110° [3]At 100° [4]Above 100°

Analyses of rocks of the Leadville, Tenmile, and Breckenridge districts

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SiO_2	55.44	56.62	57.35	63.02	63.66	64.28	64.81	65.94	66.45	67.01	67.29	67.53	68.10	68.14	68.30	68.60	70.74	73.50	74.45
	.919	.938	.951	1.045	1.055	1.066	1.074	1.093	1.102	1.111	1.115	1.120	1.129	1.130	1.136	1.137	1.173	1.218	1.241
Al_2O_3	14.95	16.74	16.29	17.61	17.05	16.99	15.73	16.00	15.84	18.03	15.78	15.46	14.97	15.29	16.24	16.21	14.68	14.87	14.72
	.146	.164	.159	.172	.167	.167	.154	.156	.155	.176	.154	.151	.146	.150	.159	.158	.144	.146	.144
Fe_2O_3	4.37	4.94	3.15	1.78	1.97	2.59	1.68	.60	2.59	.66	1.86	2.18	2.78	.35	1.60	1.67	.69	.95	none
	.027	.030	.019	.011	.012	.016	.010	.003	.016	.004	.011	.014	.017	.002	.010	.010	.004	.006	
FeO	5.18	3.27	4.36	2.76	2.62	2.64	2.91	1.74	1.43	.72	1.97	2.42	1.10	1.66	1.63	1.57	.58	.42	.56
	.072	.046	.060	.038	.036	.037	.040	.024	.020	.010	.028	.033	.015	.023	.022	.021	.008	.006	.008
MgO	3.58	4.08	2.41	1.63	1.99	1.13	2.82	1.02	1.21	.84	.72	.16	1.10	.26	1.05	1.05	.28	.29	.37
	.088	.102	.059	.040	.049	.028	.070	.025	.030	.020	.018	.004	.027	.006	.026	.026	.007	.007	.009
CaO	6.12	7.39	5.66	3.30	3.89	3.95	4.22	2.87	2.90	3.99	2.36	3.24	3.04	3.03	2.79	2.61	4.12	2.14	.83
	.109	.132	.101	.059	.069	.070	.075	.051	.051	.071	.042	.058	.054	.054	.050	.046	.073	.038	.014
Na_2O	4.44	3.50	4.50	4.72	4.13	3.78	3.98	3.85	3.92	4.42	3.77	3.24	3.46	3.59	3.90	3.29	2.29	3.46	3.97
	.071	.056	.072	.076	.066	.061	.064	.062	.063	.071	.061	.052	.055	.058	.063	.053	.037	.056	.064
K_2O	2.83	1.97	3.39	3.23	3.09	3.51	1.43	4.56	2.89	3.53	3.55	3.86	2.93	4.07	3.52	3.88	2.59	3.56	4.53
	.030	.021	.036	.034	.032	.037	.015	.048	.031	.037	.038	.041	.031	.043	.037	.041	.027	.038	.048
H_2O	.96	.92	.85	2.03	1.19	.32	.62	1.13	.84	.91	2.10	.78	1.28	.79	1.71	.92	2.09	.90	.66
TiO_2	1.22		1.07			.49	.08		.10			.41	.07	.36					
	.015		.013			.006			.001										
ZrO_2	none		trace								none	.02		.01					
CO_2	.35	1.15	.46				1.08	1.55	1.35			.03	.92	.22		.19	2.14		
P_2O_5	.49	trace	.70	.16	.27	.32	.23	.23	.36	.10	.28	.01	.16	.17	.13	.21		none	.01
	.003					.002			.002		.002								
Cl						F .06	.04	.03	.05			F .03	.03			.03	trace		
						.003													
FeS_2	.09		.09				.90	.60				.09		1.52					
MnO	.22	.15	.12	trace	.14	.14	.08	.14	.09	.09	.21	.10	.09	.12	.12	.09	.06	.03	.28
	.003					.002			.001		.003								.004
BaO	.16		.10	.08		.10				.10	none	.07		.03	trace		.03		
	.001																		
SrO	.04	trace	.05		.08	.04	trace	trace	.07			none	.08			trace	trace	trace	
	100.44	100.73	100.55[1]	100.32	100.08	100.38[2]	100.61	100.26	100.09[3]	100.40	100.16	99.63	100.11	99.65[4]	100.03	100.32	100.29	100.12	100.38

[1]Trace of V_2O_3 [2]0.03 V_2O_3 [3]Trace Li_2O [4]0.01 NiO

1.[1] Quartz diorite. *Shoshonose.* Lost Mountain.

2. Andesite. *Shoshonose.* Jennings Gulch.

3. Quartz diorite (monzonitic). *Shoshonose.* Monarch.

4. Pomeroy quartz monzonite. *Amiatose.* Pride of the West tunnel, Pomeroy Mountain.

5. Quartz latite porphyry. *Toscanose.* Mohammed tunnel, Middle Fork.

6. Etna quartz monzonite porphyry. *Toscanose.* Clover Mountain.

7. Princeton quartz monzonite. *Toscanose.* Taylor Mountain.

8. Quartz monzonite gneiss. *Toscanose.* Jennings Gulch.

9. Granite. *Liparose.* Browns Gulch.

10. Porphyrite. *Yellowstonose.* Storm Ridge. L. G. Eakins, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 227; Washington, H. S., Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 188; Clarke, F. W., Bull. U. S. Geol. Survey No. 419, 1910, p. 111.

11. Diorite. *Tonalose.* Brush Creek. L. G. Eakins, analyst. Cross, Whitman, Bull. U. S. Geol. Survey No. 150, 1898, p. 242; Washington, H. S., op. cit., p. 234; Clarke, F. W., loc. cit.

12. Porphyritic diorite. *Yellowstonose.* Mount Marcellina. T. M. Chatard, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 227; Washington, H. S., op. cit., p. 188; Clarke, F. W., loc. cit.

13. Hornblende-mica porphyrite. *Adamellose.* Cliff Creek. W. F. Hillebrand, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 227; Washington, H. S., op. cit., p. 222; Clarke, F. W., loc. cit.

14. Quartz porphyrite. *Amiatose.* Mount Carbon. T. M. Chatard, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 227; Washington, H. S., op. cit., p. 182; Clarke, F. W., loc. cit.

15. Quartz porphyrite. *Lassenose.* Crested Butte. L. G. Eakins, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 227; Washington, H. S., op. cit., p. 176; Clarke, F. W., loc. cit.

16. Rhyolite. *Toscanose.* Round Mountain. L. G. Eakins, analyst. Washington, H. S., op. cit., p. 162; Clarke, F. W., loc. cit.

17. Rhyolite. *Alsbachose.* East Mountain. L. G. Eakins, analyst. Washington, H. S., op. cit., p. 136; Clarke, F. W., loc. cit.

18. Diorite porphyry. *Andose.* Wellington mine, Breckenridge district. W. T. Schaller, analyst. Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 62.

19. Hornblende-mica porphyrite. *Andose.* Buckskin Gulch, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 340; Washington, H. S., op. cit., p. 276; Clarke, F. W., op. cit., p. 109; Ransome, F. L., loc. cit.

20. Diorite porphyry. *Andose.* Wellington mine, Breckenridge district. W. T. Schaller, analyst. Ransome, F. L., loc. cit.

21. Diorite porphyry, McNulty type. *Lassenose.* Tenmile district. L. G. Eakins, analyst. Washington, H. S., op. cit., p. 174; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

22. Quartz-hornblende-mica porphyrite. *Yellowstonose.* Gold Hill, Tenmile district. W. F. Hillebrand, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 227; Washington, H. S., op. cit., p. 186; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

23. Quartz monzonite porphyry. *Amiatose* near *Yellowstonose.* Mount Guyot, Breckenridge district. R. C. Wells, analyst. Ransome, F. L., loc. cit.

24. Biotite porphyrite. *Tonalose.* North Mosquito Amphitheater, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 340; Washington, H. S., op. cit., p. 232; Clarke, F. W., op. cit., p. 109; Ransome, F. L., loc. cit.

25. Granite porphyry. *Toscanose.* Jefferson tunnel, Tenmile district. W. F. Hillebrand, analyst. Washington, H. S., op. cit., p. 162; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

26. Lincoln porphyry. *Lassenose.* Mount Lincoln, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 332; Washington, H. S., op. cit., p. 174; Clarke, F. W., op. cit., p. 108; Ransome, F. L., loc. cit.

27. Diorite porphyry. *Yellowstonose.* Copper Mountain, Tenmile district. L. G. Eakins, analyst. Washington, H. S., op. cit., p. 186; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

28. Quartz porphyrite. *Toscanose.* Sugarloaf, Tenmile district. L. G. Eakins, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 227; Washington, H. S., op. cit., p. 162; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

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[1] Nos. 1 to 9 are analyses of rocks of the Monarch district, by R. M. Butters.

29. Quartz monzonite porphyry. *Amiatose* near *Toscanose*. Brewery Hill, Breckenridge district. R. C. Wells, analyst. Ransome, F. L., loc. cit.

30. Gray porphyry. *Yellowstonose*. Johnson Gulch, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 332; Washington, H. S., op. cit., p. 176; Clarke, F. W., op. cit., p. 109; Ransome, F. L., loc. cit.

31. Quartz monzonite porphyry. *Toscanose*. Browns Gulch, Breckenridge district. R. C. Wells, analyst. Ransome, F. L., loc. cit.

32. Quartz porphyrite. *Lassenose*. Chicago Mountain, Tenmile district. W. F. Hillebrand, analyst. Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 227; Washington, H. S., op. cit., p. 176; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

33. Granite porphyry. *Toscanose*. McNulty Gulch, Tenmile district. W. F. Hillebrand, analyst. Washington, H. S., op. cit., p. 162; Clarke, F. W., op. cit., p. 110; Ransome, F. L., loc. cit.

34. White porphyry (not fresh). *Riesenose*. California Gulch, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 326; Washington, H. S., op. cit., p. 138; Clarke, F. W., op. cit., p. 108; Ransome, F. L., loc. cit.

35. Mount Zion porphyry. *Toscanose*. Prospect Mountain, Leadville district. L. G. Eakins, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 326; Washington, H. S., op. cit., p. 162; Clarke, F. W., op. cit., p. 108; Ransome, F. L., loc. cit.

36. Nevadite. *Liparose*. Chalk Mountain, Leadville district. W. F. Hillebrand, analyst. Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, p. 349; Bull. U. S. Geol. Survey, No. 150, 1898, p. 164; Washington, H. S., op. cit., p. 148; Clarke, F. W., op. cit., p. 109.

Of the nine types analyzed, five have essentially the chemical composition of medium-acid to acid quartz monzonite (Brögger's banatite and adamellite). These differ chiefly in the proportion of silica, alumina, and lime. Three of the five—the quartz monzonite, quartz monzonite gneiss, and Etna porphyry—differ but little throughout. The quartz diorite is also chemically monzonitic, but the considerable development of biotite, owing probably to the high content of alumina and ferrous oxide, materially reduced the potash available for the formation of orthoclase, and the high alumina and lime resulted in the development of much of the anorthite molecule. The rock, therefore, contains too much lime-soda feldspar in proportion to orthoclase to be classed with the monzonites.

Although there are no very basic rocks in the region the silica range between the quartz diorite and granite is rather wide. The diagram shows the general, though not uniform, decrease in alumina, lime, magnesia, and ferrous iron, with increasing silica. The total alkalis are fairly high and, in general, increase slightly with increasing silica. Soda and potash are commonly nearly equal in amount.

Considered in phases, there is a more uniform variation in chemical composition from the less acid to the more acid rocks. This progressive change is brought out in figures 6 and 7. The composition of the Pomeroy quartz monzonite causes considerable

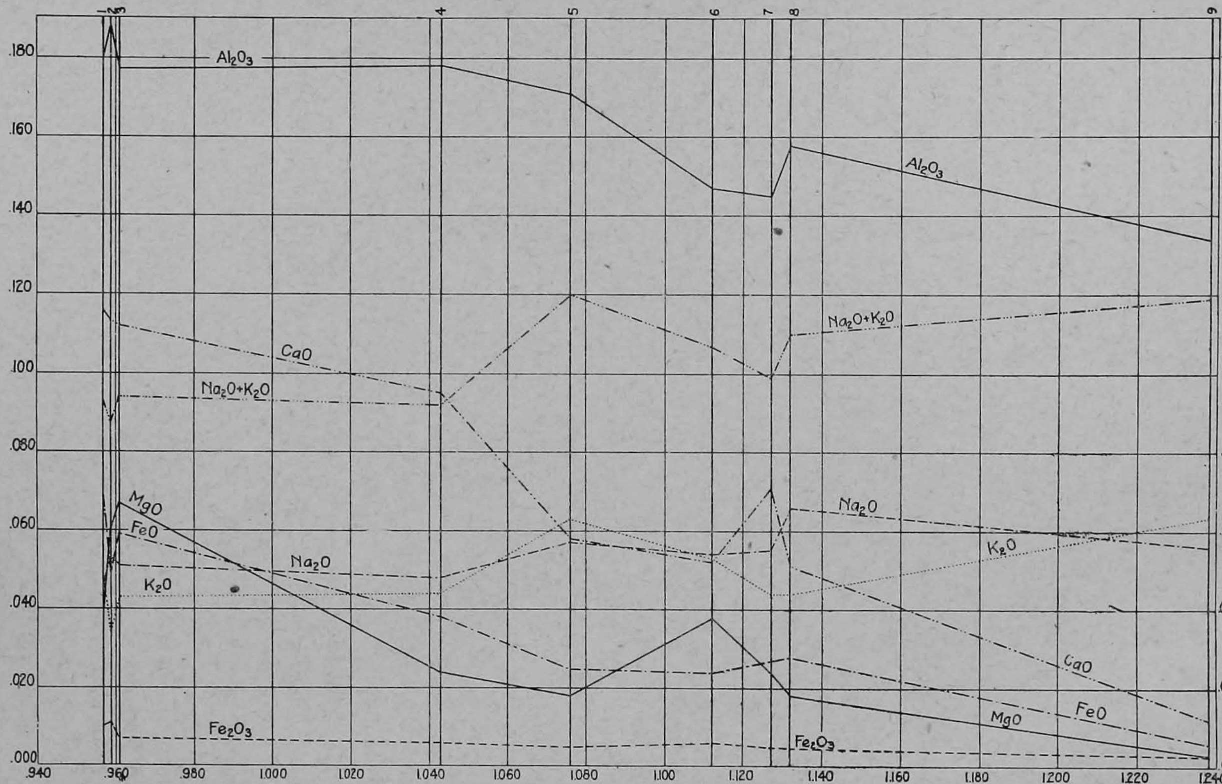


Figure 5.—Diagram showing variation of molecular constituents of nine rocks of the Monarch district. Numbers at top correspond to analyses of table.

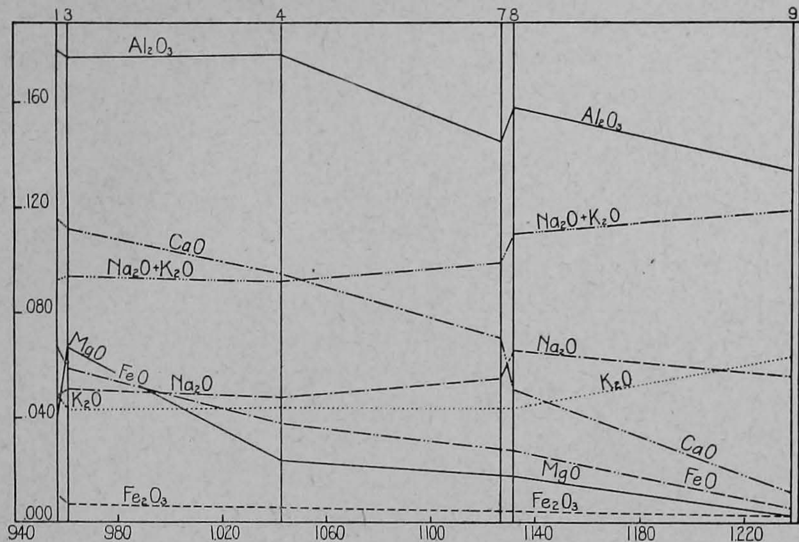


Figure 6.—Variation diagram of six plutonic rocks of the Monarch district. Numbers as in Figure 5

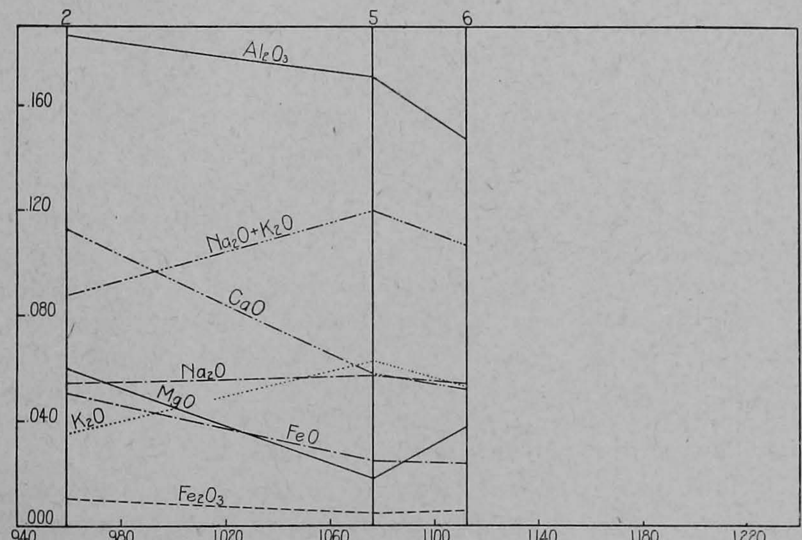


Figure 7.—Variation diagram of three rocks of the phase of minor intrusions of the Monarch district. Numbers as in Figure 5.

irregularity in the curves. The gneiss, which is older than the Princeton quartz monzonite, contains a little more silica than the analyzed specimen from Taylor Mountain, which is probably somewhat lower in silica than the quartz monzonite a few miles farther north.

The phase of minor intrusions shows a much more uniform progressive variation in all the oxides than does the plutonic phase (fig. 7). The diagram lacks a member, however, corresponding to the granite of the plutonic phase. An analysis of one of the rhyolites would perhaps not differ greatly from that of the granite, but the volume of the rhyolites is small, and their exact position in the chronological series is not known. Even with this exception, the two diagrams not only show the general increase in silica content of the rocks during each phase, but also a marked stability of the average magma during the two phases which doubtless extended through a considerable period.

Although no analyses of the dike-rocks have been made, microscopic study shows that they must have nearly the same chemical range as the plutonic rocks. The order of intrusion of the dikes is not known. Marked diaschistic or complementary dikes are not noticeably present in the region.

COMPARISON WITH OTHER COLORADO ROCKS

A number of the supposed Tertiary igneous rocks of the Elk and West Elk mountains and the Leadville, Tenmile, and Breckenridge districts of central Colorado have been analyzed by the United States Geological Survey. Eighteen analyses of porphyries of the Leadville, Tenmile, and Breckenridge districts, which are in one general region, have been brought together in a table and diagram by Ransome,[1] who points out their close relationship.

The present writer has added the analysis of the Chalk Mountain nevadite to Ransome's diagram, and combined this modified diagram (18-36) and one showing the variation in the rocks of the Elk and West Elk mountains (10-17) with the variation diagram of the Monarch rocks (Pl. XVIII).

These three groups of rocks are not far removed from one another in space, and very probably all belong to the same general

[1] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: Prof. Paper U. S. Geol. Survey No. 75, 1911, pp. 60-62.

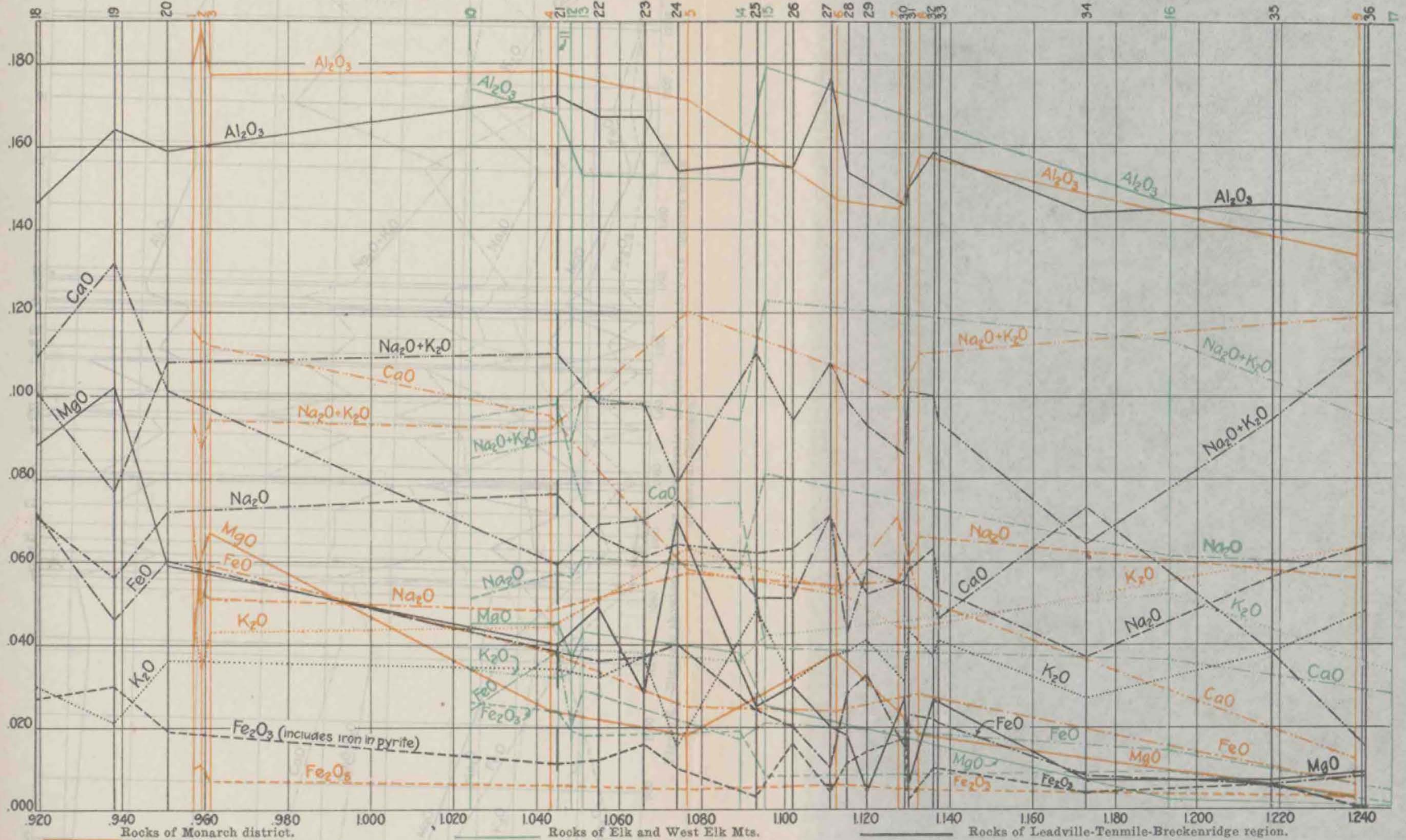


DIAGRAM SHOWING VARIATION OF MOLECULAR CONSTITUENTS OF ROCKS OF CENTRAL COLORADO

Numbers at top correspond to numbers of analyses of tables.

(7)

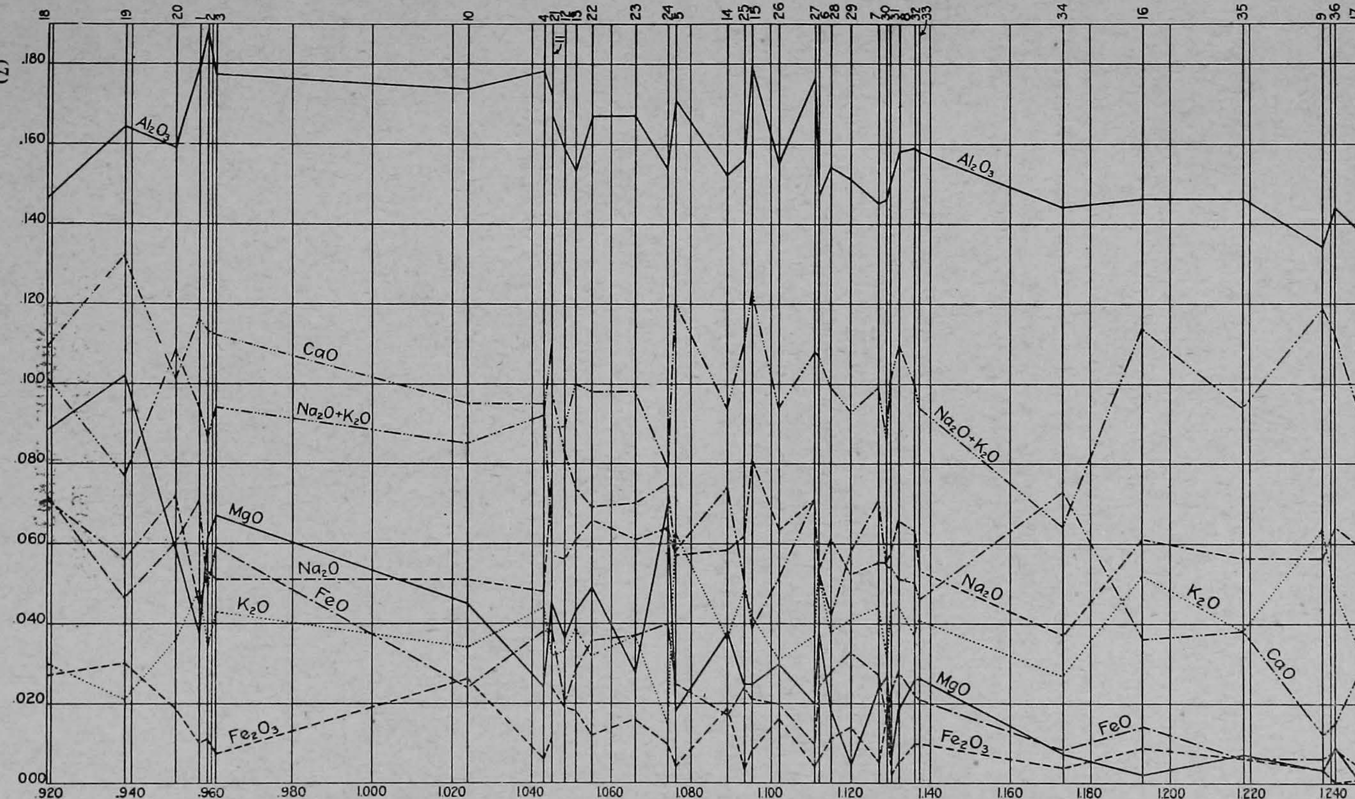


Figure 8.—Diagram showing variation of molecular constituents of thirty-six igneous rocks of central Colorado.

period of vulcanism. Though there are a number of minor differences the general similarity of the three groups is obvious. The three diagrams are condensed in figure 8, which shows that, in general, the differences between rocks of the different regions are not greater than those between rocks of the same region. Both chemically and mineralogically, the resemblances among the three groups are as close as are ordinarily found among the various types of a petrographic province.

The predominance of types having the chemical composition of quartz monzonite is evident. The quantitative relation of each type to the whole is unknown, but there is little doubt that the Princeton quartz monzonite greatly exceeds any other in quantity and may possibly equal all the others combined.

The textural differences are greater than the chemical and mineral differences. While the rocks of the Monarch region probably present far the greatest variety in texture, they have some textural features in common with the rocks of the Elk and West Elk mountains, and others in common with the rocks of the Leadville-Tenmile-Breckenridge region. Certain porphyritic textures are common to the three groups.

CHAPTER X

ECONOMIC GEOLOGY OF THE MONARCH DISTRICT

HISTORY OF MINING

In 1878 ore was discovered on the Great Monarch claim by the Boone brothers. This was followed in 1878 or 1879 by discoveries of ore, by the four Boones, on the Fairplay, Pay Master, Ben Bolt, and Eclipse. N. C. Creede (?) located the Oshkosh in 1878 or 1879. At about the same time Smith and Gray discovered ore in the Madonna and Silent Friend. Early in 1879 Daily found ore at Cree Camp on the Song Bird claim, which he afterward sold to Alex Cree. The Mountain Chief, Missouri Boy, Eagle Bird, and others in Taylor Gulch, were soon located.

About 1878 a company was organized to prospect Pomeroy Mountain. A large force was set at work driving the Pride of the West tunnel at the head of North Fork. The equipment was the best that could be had at that time, and no expense was spared to make the surroundings attractive to the workmen. The work of the company stimulated prospecting throughout the North Fork valley and Shavano soon became a flourishing settlement. In 1881 the railroad was built to Maysville which became a prosperous town, the site of two small smelters, and the supply point for the North Fork country as well as the South Fork, Middle Fork, and Taylor Gulch areas. The double-track Pride of the West tunnel was driven into Pomeroy Mountain nearly 1,300 feet. Having found no ore of shipping grade the company suddenly suspended work, and the North Fork valley was soon practically deserted.

Meanwhile prospecting continued in the vicinity of Monarch, and several properties early began to produce ore. The first ore shipped from this part of the district came from the Great Monarch mine and was hauled by wagon to Canon City. It carried about 200 ounces silver per ton. A small amount of ore from other mines was freighted by wagon to Canon City before the railroad was built to Maysville. The ore from most of the mines was of too low grade to ship after hauling by wagon even to Maysville. The owners of the Madonna, to whom the discoverers sold that claim, built a small smelter at the foot of the hill to treat the Madonna ores, but this was not a success. In 1883, A. Eilers saw the possibilities of the Madonna mine, secured the extension of the railroad from Maysville to Monarch—a distance of nine miles—and organized the Colorado Smelting Company, which took over the Madonna mine and erected the Colorado smelter at Pueblo. Since an abundance of basic ore was supplied by the Madonna for fluxing siliceous ores purchased from other Colorado districts, this enterprise was a success from the first.

For about ten years, beginning with 1883, the production of the district was large. In 1893 Monarch shared the common experience of Colorado silver-producing camps, and for some time the district was nearly deserted. Within the past few years, however, with a home market for zinc and an increasing demand for basic fluxing ores, there has been a revival of interest in the district. The year 1910 was the best year in the history of the district since the eighties. Like many other mining camps of the West in 1911 the district was quiet; this was in large measure owing to the inability of the Monarch-Madonna Mining Company to handle the water in the winze below No. 6 level of the Madonna mine, with the available equipment. In 1912 development work progressed vigorously; good ore was opened up in the Garfield mine, several carloads of good ore were shipped from a recently-discovered body in the New York mine, payable ore was uncovered in the Eclipse mine, and a body of high-grade ore was partly blocked out on the lowest levels of the Madonna mine when an accident to the pump caused a temporary suspension of work.

That the production of the region has not been greater is due in part to the methods of a number of mine owners who have been satisfied to acquire modest fortunes with the least possible risk. Very little development work was carried on in the early days in some of the good mines while ore was being taken out, and they were closed when the known ore bodies began to fail. To the credit of the district it should be stated that there has been a minimum of expensive litigation among the mine owners. Probably not more than two mines have ever been shut down pending court decisions.

PRODUCTION

Since there have been so many estimates, guesses, and exaggerated statements as to the output of the district a special effort has been made by the Survey to secure data which would be reasonably accurate. Many of the mine owners have co-operated, and the result is fairly satisfactory. The tonnage and value, by years, have been obtained for the Eclipse, Fairplay, Lilly, and Madonna mines, but in most instances only the total production could be learned. Conservative estimates have been accepted for a few mines of which the exact output was not known.

The district has produced ore having a gross value of probably not less than $9,000,000, and possibly $10,000,000. Of this amount the Madonna mine has produced nearly $5,000,000. The production of several others is mentioned in the description of the mines.

WATER SUPPLY AND TIMBER

Precipitation during the winter is heavy, and the snow that accumulates on the highest slopes may remain until nearly the end of summer. The melting snow and frequent showers furnish abundant water within the district for every purpose during the summer. In the winter the streams are continually fed by numerous springs.

Formerly pine, spruce, and fir covered most of the slopes below timber line, but much of the timber is now removed. Although a few restricted areas are still densely forested, the renewal of a demand, such as existed in the eighties, would soon exhaust the supply in the immediate vicinity of the mines. Even now a large part of the timber used comes from near Leadville.

GROUND WATER

Owing probably to the high relief of the region and the broken and readily soluble character of the rocks, the level of the ground water in the sedimentary area is low. It has probably not yet been reached by any mine in the district excepting possibly the Columbus, Fairplay, and Madonna mines. During the long winters when the ground is frozen and precipitation takes the form of snow the mines are comparatively free from water. Even the winze below No. 6 level of the Madonna mine was sunk 155 feet in dry ground though it perhaps reaches a depth of 50 feet or more below the level of the creek which is less than half a mile away. The bottom of the winze is about 800 feet vertically below the surface. The Eclipse mine on the slope of Monarch Hill has reached a vertical depth of 800 feet in dry ground, below the surface. Near the head of Taylor Gulch, the bottom of a winze sunk 200 feet or more below the tunnel level of the Lilly mine is about 800 feet below the surface and the same depth below the level of the creek at Cree Camp about 1,500 feet distant; yet there has never been a pump in this mine and the winze has been nearly free from water even during the rainy seasons. In the sedimentary area of the district, therefore, it is safe to say that the level of ground water is generally at least 800 feet below the surface. Near the permanent streams it is, of course, probably near the surface.

No information concerning the depth of the level of ground water in the igneous and regionally-metamorphosed rocks is available. During the summer, water flows continuously from the Columbus tunnel in a fissure vein which is in the Princeton quartz monzonite, on the south slope of Taylor Mountain. But in view of the summer rains and the great volume of melting snow this fact probably has no significance.

During the seasons of rain and of melting snow, ground water is present at almost any level of most of the mines. In places the volume is considerable though generally not enough to materially increase the cost of mining. Though the ground water increases the weight of most of the ore, the slight disadvantage of a high moisture content is perhaps many times compensated by the lengthened life of mine timbers in wet mine workings. The only place where the water has seriously interfered with mining is below No. 6 level of the Madonna mine. Manager Burton estimates that with pump and bucket water was raised from this winze at the rate of at least 175 gallons a minute during the first part of the summer of 1912.

THE ORE DEPOSITS

SURFACE INDICATIONS OF ORE BODIES

The first ore that was discovered in the district—that on the Great Monarch claim—outcropped between black dolomite walls in the cliff about a quarter of a mile east of Monarch. Here rich silver ore was in contact with dark gray to black smithsonite. On the Madonna, Eclipse, Lilly, Last Chance, and Exchequer claims much limonite (gossan) may be seen at the surface. Limonite in smaller quantity is found at the surface on a few other claims. Manganese dioxide is at or near the surface on a few claims that have produced ore. Copper slightly stains the rocks along the limestone-granite contact on the southwest slope of Missouri Hill above the ore bodies of the Clinton mine.

Some of the fissure veins of the unglaciated areas show only an outcrop of barren quartz; others carry considerable limonite.

Sulphide minerals with quartz are exposed in a few of the fissure veins in the glaciated areas.

CHARACTER OF THE ORES

Most of the known ore of the Monarch district is basic ore, and nearly all that is now being mined is shipped, without treatment, directly to the smelters. A little silica from altered chert is present in the replacement deposits in limestone, and the border of ore shoots in immediate contact with granite as, for example, that on the No. 6 level of the Madonna mine, is likely to run high in silica. Quartz is found with but few important ore bodies except those in fissure veins. Silicates have been found in a few contact deposits. Aside from the lime which materially increases the basicity of some of the ores, there is generally more than enough iron to satisfy the silica present. The "excess iron" commands a price dependent on the demand for basic ores. By excess iron is meant the quantity present after deducting sufficient, as determined by assays, to satisfy the silica content. Manganese in oxide form in the Mason, Clinton, and Rainbow-Eagle Bird mines increases the value of the ore by lessening the treatment charges.

Hitherto the greater part of the product of the district has been oxidized ore, chiefly silver-bearing lead carbonate, in which bunches of sulphide have been found at any depth.

Monarch Hill produces mainly ores of lead, silver, gold, and zinc, with some copper in the Madonna and Eclipse mines. The ores of Taylor Gulch are of copper, silver, gold, lead, and zinc. Columbus Gulch has produced silver, gold, copper, and lead. The Middle Fork ores are chiefly of silver, gold, and lead. The mines and prospects of North Fork have produced chiefly silver and lead. Molybdenum is present in Browns Gulch.

During the period of greatest activity in this district there were no zinc smelters in Colorado, and much zinc ore was left in the mines. Part of this is now being taken out. The silver of much of the silver-zinc and silver-lead-zinc ores was recovered by mixing these ores with ores of lead and of silver and lead and at the same time keeping the zinc content below the limit fixed by the smelters.

TENOR OF THE ORES

Since so few records of tonnage and values have been kept it is impossible to determine the exact average value of the ores. An estimate of the average value based on data in hand from a number of mines would be about $20 to $25 per ton for the ores of Monarch Hill and considerably higher for those of Taylor Gulch. The comparatively small tonnage from near the head of Middle Fork must have averaged considerably higher in value than the ores of Monarch Hill or it could not have been profitably mined. The ore in the present workings of the mines of North Fork could not be profitably mined without concentrating. The report of the Director of the Mint, for 1882, states that the Columbus ore would average $40 per ton, while a considerable amount mined in 1880, carried 1,200 ounces silver. The Madonna ores have averaged about $24 per ton. The copper ores of the Lilly mine average about 10 per cent copper. Basic ore worth $7.00 a ton net—that is, above freight and treatment charges—can be mined at a profit under present conditions.

The range in value is very great—about $5.00 to $5,000.00 per ton. A few carloads shipped from the district have returned about $1.00 a ton after paying freight and treatment charges. On the other hand, a carload from the Fairplay mine carried 130.75 ounces silver per ton, 39.95 per cent zinc, and 10.05 per cent lead. The best carload from the Little Charm mine returned from the smelter .48 ounces gold and 226.2 ounces silver per ton, and 24.5 per cent lead. A sample from the Rainbow-Eagle Bird mine assayed .26 ounces gold and 3,180 ounces silver per ton. A sample from a streak one to six inches wide on the lowest level of the Madonna mine, assayed for the Survey by H. F. Watts, of Boulder, carried 65.10 ounces gold and 5,974.9 ounces silver per ton and 24.3 per cent lead.

The moisture content ranges from 5 to 20 per cent. The greater part of the ores carries between 10 and 14 per cent moisture.

MINERALOGY OF THE ORES

In describing the minerals it is intended to mention only those characters which the minerals of the district possess. Some of the metallic minerals listed here are not found in this region in sufficient quantity to be considered ores, as, for example, wulfenite and molybdic ocher. The iron and manganese minerals are included in the list because, by virtue of their fluxing properties, they add to the value of the ores. For the convenience of miners and prospectors who may not have at hand a text-book of mineralogy the percentage of the principal metal of each mineral is given. The minerals are arranged alphabetically under the name of the characteristic metal of each group. Of the metallic minerals observed, several are primary—that is, were deposited originally in the condition in which they are now found. These are: hematite, magnetite, pyrite, pyrrhotite, galena, molybdenite, and sphalerite. Secondary minerals—those derived from others—are more numerous in the district. Those which are secondary in the occurrences noted are: azurite, chalcocite, chrysocolla, native copper, cuprite, malachite, tenorite, limonite, turgite, anglesite, cerussite, wulfenite, psilomelane, pyrolusite, molybdite, argentite, cerargyrite, native silver, calamine, and smithsonite. It is not known whether the bornite and chalcopyrite observed in small quantity are primary or secondary.

COPPER

Azurite, basic cupric carbonate, $2CuCO_3.Cu(OH)_2$—copper 55.3 per cent. This mineral occurs as a blue coating on surfaces of jointed limestone, and it is also disseminated in the mineralized limestone near the copper-ore bodies. It is also present in massive form associated with malachite. It is quite common in the Lilly and Major mines.

Bornite, copper-iron sulphide, Cu_3FeS_3—copper 55.5 per cent. Bornite occurs in small quantity in pegmatitic quartz on the Highland claim south of the South Arkansas.

Chalcocite, cuprous sulphide, Cu_2S—copper 79.8 per cent. Good chalcocite was seen by the writer only in the Hercules tunnel where it fills a narrow fissure in the quartz monzonite. It is nearly black, and friable.

Chalcopyrite, copper-iron sulphide, $CuFeS_2$—copper 34.5 per cent. This mineral occurs in the lower workings of the Lilly and probably in the Columbus. It is brass-yellow and massive.

Chrysocolla, copper silicate with water, $CuSiO_3.2H_2O$—copper 36.1 per cent. This is found as a sky-blue mineral coating the walls of small cavities in the Lilly mine and filling narrow fissures in other copper ores.

Copper, native, Cu. Native copper was found near the surface in the Lilly mine and has also been reported from the Columbus mine.

Copper-bearing pyrite, sulphide of iron with a variable amount of copper, FeS_2. It is found in the Lilly mine in bunches surrounded by oxide of iron derived from it. It is also found in several prospects. It is massive and brass-yellow; sometimes it shows purple tarnish.

Cuprite, cuprous oxide, Cu_2O—copper 88.8 per cent. This is present in the Lilly mine both as a soft red mineral intimately associated with iron oxide, and as purer, harder, crystallized mineral.

Malachite, basic cupric carbonate, $CuCO_3.Cu(OH)_2$—copper 57.54 per cent. This green carbonate is present in nearly all the mines which have produced copper, particularly the Lilly and the Madonna. It is found in considerable quantity associated with other oxidized copper minerals and disseminated through the limestone, as a replacement, in sufficient quantity to make payable ore. In the mineralized portions of the gneiss, pegmatite, and basic syenite dikes it is not uncommon as a stain.

Tenorite, cupric oxide, CuO—copper 79.8 per cent. The hard lustrous black oxide of copper has been found in the Major and the New York mines. It is associated with the carbonates and contains considerable iron. The earthy form, *melaconite,* occurs with copper carbonates in the Lilly and the Major mines.

GOLD

Native gold has been reported from the Rainbow-Eagle Bird mine. It is probable that it also occurs in most of the oxidized ores that carry gold, but the mineral has not been detected. Some of the Madonna ores are said to have contained specks of a white mineral, and from samples containing this mineral several assayers have reported tellurium. One determination gave three per cent tellurium. It is therefore probable that telluride exists in some of the ores. The writer, however, has been unable to find tellurium in the high-grade oxidized ore from the lower levels of the Madonna mine.

IRON

Hematite, ferric oxide, Fe_2O_3—iron 70 per cent. Hematite was not seen associated with the ores, but much black specular hematite is present on a dump a few yards south of the Ingersoll shaft. A large part of the mineral is practically pure. Specular hematite was also found on a dump on or near the Pay Master claim on Monarch Hill.

Limonite, ferric oxide with water, $2Fe_2O_3.3H_2O$—iron 59.8 per cent. Brown limonite and, to a less extent, the yellow ocherous variety occur in nearly every ore-body discovered. Much of it carries a small quantity of silver. Very large bodies of limonite are present in the Madonna mine.

Magnetite, a compound of ferrous oxide and ferric oxide, $FeO.Fe_2O_3$—iron 72.4 per cent. This mineral was not seen by the writer in any of the ore deposits, but it is said to have been associated with the Mountain Chief ores. It may be seen south of the Mountain Chief tunnel on the Clinton mine dumps, on the southeast slope of Taylor Mountain, and as a vein two or three feet wide just east of Boss Lake.

Pyrite, iron disulphide FeS_2—iron 46.6 per cent. Both as crystals and in the massive form pyrite is found in the Lilly and Garfield, in smaller quantity in the Madonna, and perhaps in other mines in the sedimentary rocks. Its rarity on Monarch Hill is explained by the fact that nearly all the ore mined comes from the zone where the pyrite has been oxidized to limonite. In the fissure veins it is a very common mineral.

Pyrrhotite, iron sulphide, chiefly $Fe_{11}S_{12}$—iron about 60 per cent. This bronze-yellow to brown mineral, in massive form, is associated with galena, blende, and pyrite in the Garfield mine. East of Boss Lake it is associated with fluorite and coarse calcite in baked shale.

Turgite, hydrous ferric oxide, $2Fe_2O_3.H_2O$—iron 66.2 per cent. Red, earthy turgite occurs with limonite in the Madonna mine below No. 5 level.

LEAD

Anglesite, lead sulphate, $PbSO_4$—lead 68.3 per cent. In the summer of 1909, Mr. Thomas Penrose found in the Little Wonder mine a small group of anglesite crystals near the center of a mass of galena weighing several hundred pounds. These crystals had a dull surface, owing perhaps to the formation of carbonate, but within, the mineral was pure, water clear anglesite. The largest crystal was nearly two inches long.

Cerussite, lead carbonate, $PbCO_3$—lead 77.5 per cent. This mineral, in the form of soft carbonate with an admixture of limonite and carrying silver, has been produced in far greater quantity than any other mineral in the district. Hard carbonate occurs in only a few of the ore bodies. Crystallized cerussite has been found in the Mason and the Lilly mines, in the lower workings of the Madonna, and as a coating on galena in several mines.

Galena, lead sulphide, PbS—lead 86.6 per cent. Coarsely crystallized galena is present in practically all the mines that have produced lead.

Wulfenite, lead molybdate, $PbMoO_4$—lead 56.4 per cent. This mineral was not seen in any of the mines, but a specimen found on the Hawkeye dump contained many yellow tabular crystals of wulfenite coating galena.

MANGANESE

Psilomelane, perhaps H_4MnO_5—manganese nearly 40 per cent. Psilomelane occurs as a black, hard, massive mineral in the Mason, Rainbow-Eagle Bird, and possibly other mines.

Pyrolusite, manganese dioxide, MnO_2—manganese about 79 per cent. Pyrolusite, in earthy form, is found with psilomelane in the Rainbow-Eagle Bird mine and possibly without psilomelane in the Delaware mine.

MOLYBDENUM

Molybdenite, molybdenum disulphide, MoS_2—molybdenum 60.0 per cent. This mineral is found north of Browns Creek just without the area mapped and it has also been reported from Hoffman Park. Near Browns Creek the molybdenite occurs in small tabular crystals associated with quartz, white mica, pyrite, and molybdite in a vein in the Pomeroy quartz monzonite.

Molybdite, or *molybdic ocher,* $Fe_2(MoO_4)_3.7\frac{1}{2}H_2O$[1]—molybdenum 39.6 per cent. This mineral is found as an oxidation product of the molybdenite (and probably pyrite) of Browns Creek where it forms a yellow powdery material on both the surface vein minerals and the wall rock. The microscope shows the molybdite to be made up of fibrous crystals.

Wulfenite. This mineral was included with the lead minerals.

SILVER

The rich silver ore of most of the mines was produced many years ago, and good specimens are now scarce. Recently, however, specimens of high-grade ore from the Madonna and Moose mines have afforded determinable silver minerals.

Argentite, silver sulphide, Ag_2S—silver 87.1 per cent. A small specimen of practically pure, well-crystallized argentite from the

[1]See Schaller, W. T., The chemical composition of molybdic ocher: Am. Jour. Sci. 4th series, vol. 23, 1907, pp. 297-303; Bull. U. S. Geol. Survey No. 490, 1911, pp. 84-92.

Moose mine was recently seen by the writer. The Columbus and Rainbow-Eagle Bird mines are reported to have produced argentite. The high grade ore from the lowest level of the Madonna mine contains much argentite in grains which can be seen under a strong lens.

Cerargyrite, or *horn silver,* silver chloride, AgC1—silver 75.3 per cent. Silver chloride having a copper stain has been reported from the Little Charm and the Mountain Chief mines. The high-grade ore from the lowest level of the Madonna contains abundant silver chloride which is determinable only by its solubility in ammonia. The ore, which is earthy, does not show the mineral when examined under a lens.

Silver, native, Ag. Native silver was seen in a specimen from the Moose mine. It probably occurred also in the oxidized silver-lead ores that have been produced by all the larger mines of the district.

Stephanite, silver sulphantimonite, Ag_5SbS_4—silver 68.5 per cent. Stephanite is said to have been found in the Little Charm mine.

ZINC

Calamine, hydrous zinc silicate, $H_2Zn_2SiO_5$—zinc 54.2 per cent. Calamine in small tabular crystals occurs in narrow veins in the smithsonite. A part of the massive zinc mineral with which the crystals are associated may also be calamine.

Gahnite, or *zinc spinel,* zinc aluminate, $ZnAl_2O_4$—zinc 35.5 per cent. Dark green zinc spinel is found in small quantity in the Bon Ton vein, and in less quantity as a constituent of the garnetiferous schist nearby. In the vein, it is associated with quartz, feldspar, chalcopyrite, zinc blende, and galena. The spinel forms half, or more, of the volume of some specimens, but is commonly less abundant. It occurs in grains and rhombic dodecahedrons, which have a maximum diameter of about one-fourth inch. The dodecahedrons are rare. Chemical tests of the gahnite show the presence of magnesium and iron.

Smithsonite, zinc carbonate, $ZnCO_3$—zinc 52.2 per cent. This is the most common zinc mineral which the district is now producing. It occurs as a hard massive, dark gray mineral, as a softer yellowish to brownish mineral, and as small crystals in vugs and narrow veins.

Sphalerite, or *zinc blende,* zinc sulphide, ZnS—zinc 67 per cent. Crystals of sphalerite with galena and quartz occur in the Columbus vein. The massive mineral is found associated with galena, pyrite, and pyrrhotite in the Garfield mine, and with diopside and garnet in the New York mine.

NON-METALLIC GANGUE MINERALS

Andradite, calcium-iron silicate, $3CaO.Fe_2O_3.3SiO_2$. This garnet has been found associated with the ores of the Clinton and New York mines.

Calcite, "spar," calcium carbonate, $CaCO_3$. Coarsely crystallized calcite is common at the border of ore bodies, and is considered a favorable indication when encountered in prospecting. It is in some cases slightly mineralized, carrying small amounts of galena, pyrite, or silver mineral. Calcite is also present in considerable amount in many of the prospects in which no ore has been found.

Chlorite, chiefly a hydrous silicate of aluminum, ferrous iron, and magnesium. A pale green chloritic mineral is found in very small quantity in narrow vein-like streaks in some of the sulphide ores of the Garfield mine.

Diopside, silicate of calcium and magnesium, $CaO.MgO.2SiO_2$. Pale green diopside is associated with zinc blende in the New York mine.

Dolomite, carbonate of calcium and magnesium, $(CaMg)CO_3$. Brown, coarsely crystallized dolomite is associated with the ore of the Rainbow-Eagle Bird mine. A black to bluish-gray variety of the same mineral forms the walls of a few ore bodies on Monarch Hill.

Quartz, silica, SiO_2. Quartz in large amount is associated with the ores in the fissure veins, pegmatite, gneiss, and schist. It has also been found recently on the border of a streak of high-grade ore in the deepest workings of the Madonna mine. In the form of quartzite it forms the walls, in part, of a few replacement ore bodies.

Tremolite, a silicate of calcium and magnesium, $CaO.3MgO.4SiO_2$. Tremolite is found in considerable quantity with pockets of galena south of Greens Gulch.

TERMS USED TO DESCRIBE ORE SHOOTS

Although ore is found in bunches or pockets in a number of mines, the typical occurrence of the largest bodies is in shoots which dip at a fairly uniform angle toward the north and northwest.

The terms used in the descriptions of these shoots will be those employed by Lindgren and Ransome in their descriptions of the Cripple Creek ore shoots[1], with but one change. The terms width, thickness, stope length, pitch length, and pitch will be used. "The stope length is the distance along the drifts over which payable ore extends; the pitch length, or axial length, as it might also be termed, is the distance between the two extreme ends of the shoot; the pitch is the angle which the pitch length makes with the horizontal." Width will be understood as the horizontal distance from wall to wall at right angles to the pitch length just as it is used by the authors quoted. The distance across the shoot at right angles to the pitch length and width will be called the thickness. In the Lilly mine and in a few other instances the width is less than the thickness, but ordinarily the width is the greater; in some cases the two are equal. In many mines the stope length is identical with the width. Figure 9 will make clear the relations of the terms used.

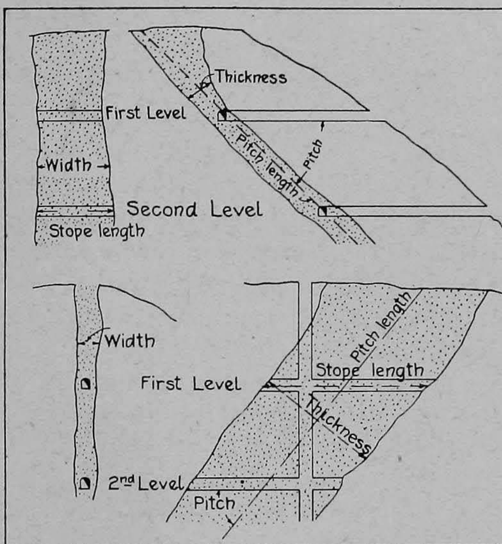


Figure 9.—Diagram to illustrate terms used in describing ore shoots. (After Lindgren and Ransome, modified to suit conditions at Monarch.)

CLASSES OF ORE DEPOSITS

With the possible exception of part of the relatively unimportant deposits in pegmatite and gneiss or schist, all the known ores

[1]Geology and Gold Deposits of the Cripple Creek District, Colorado. Professional Paper 54, U. S. Geol. Surv., pp. 205-206.

of the Monarch district are epigenetic—that is, of later age than the inclosing rock. The ores that have come under observation in the Monarch district may be grouped as follows:

1. Replacement deposits in limestone and dolomite.
2. Filling of fault fissures in the limestone and "parting quartzite" with much replacement of the wall rock.
3. Fissure veins in igneous rocks with little or no replacement of the wall rock.
4. Contact deposits.
    (a) At or near eruptive contacts with no appreciable metamorphism.
    (b) Contact-metamorphic deposits.
5. Ores in pegmatite, gneiss, and schist.

There are several interrelations and intergradations among the classes mentioned. No. 1 differs from No. 2 chiefly in that the ores of the former are probably not associated with pre-mineralization open fissures, though there may have been local faulting in some instances. Nos. 2 and 3 differ essentially in the origin of the fissures filled as well as in the absence of appreciable replacement of the wall rock of the fissure veins. The contact-metamorphic deposits differ from Nos. 1 and 2 chiefly by the presence of gangue minerals of contact-metamorphic origin, which have not been detected in the ores of Nos. 1 and 2.

REPLACEMENT DEPOSITS IN LIMESTONE AND DOLOMITE

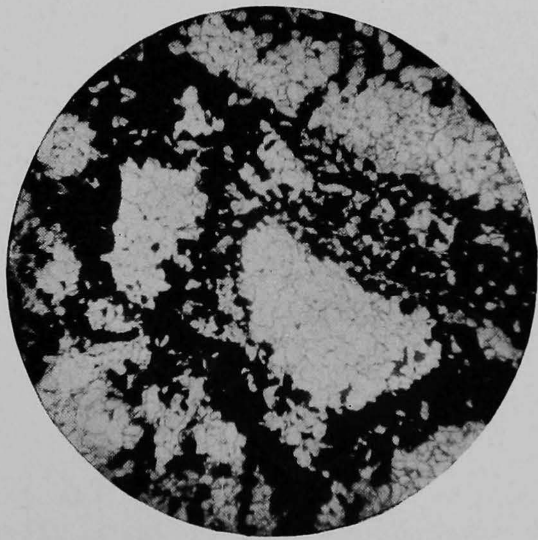
In considering these deposits, examples of certain features of the second and fourth classes, in so far as they illustrate replacement, will be cited. The simple replacement type includes chiefly the ores of the smaller mines of Monarch Hill, part of the Madonna ores, and probably part of the deposits on the east side of Taylor Gulch. The largest developed ore bodies of the replacement type are on Monarch Hill in the Ordovician limestone, not far above the pre-Cambrian granite. (See fig. 10.) Smaller bodies in the Ouray limestone have been mined. In Taylor Gulch replacement ore bodies also occur in the Garfield formation.

EVIDENCES OF REPLACEMENT

Of nine criteria of replacement that Irving[1] discusses in his paper on replacement ore bodies, five may be applied with more

[1] Irving, J. D., Replacement ore-bodies and the criteria for their recognition: Economic Geology, vol. 6, 1911, pp. 527-561, 619-669.

A.—PHOTOMICROGRAPH OF ORE FROM MONARCH CONTACT TUNNEL
Black mineral is pyrite; dark gray mineral is zinc blende; light mineral is calcite.
Ordinary light; x 16.



B.—PHOTOMICROGRAPH OF ORE FROM NEAR BOSS LAKE
Black mineral is zinc blende; dark gray mineral is galena; light mineral is dolomite.
Ordinary light; x 14.

or less certainty to the Monarch ores. These are: (1) presence of complete or partly faceted crystals in the country rock, (2) absence of intersecting concave surfaces of the limestone in contact with the ore, (3) absence of crustification, (4) unsupported structures, and (5) form of ore bodies.

Complete or partly faceted crystals in country rock.—Since nearly all of the ore minerals have been oxidized, the original sulphides are very rarely found in the wall rock of the Monarch ore bodies. Galena with cube faces was found disseminated in the limestone near the ore below No. 5 level of the Madonna mine. The remains of partly oxidized crystals of pyrite which still retained the cubic form were found near the same place. Minute cubes of pyrite may be seen disseminated in the crystalline limestone of a specimen from the Monarch Contact tunnel. A thin section (Pl. XIX, *A*.) of the same specimen shows grains of pyrite with incomplete crystal outline, while crystal forms are absent from the disseminated zinc blende in the same specimen. Pyrite, in cubes and combinations of cube and octahedron, is common in the granite and gouge near the ore bodies of several mines; here it has escaped oxidation more commonly than that in the limestone. However, the metallic minerals of the disseminated replacement ores are for the most part in formless grain. (See Pl. XIX, *B*.)

Absence of intersecting concavities.—Irving compares the surface of cavern walls in limestone with the boundary between ore and wall rock in replacement deposits. The walls of a solution-formed cavern in limestone are very likely to show a great number of intersecting concavities; these should remain if ore susequently filled the cavern. On the other hand, the outline between ore and wall rock in replacement deposits is very irregular. Such an irregular outline is found between the Monarch ore bodies and the wall rock.

Absence of crustification.—Crustification—the effect of the successive or alternate deposition of unlike minerals on the walls of openings—has not been observed in any of the ore bodies here classed as replacement deposits.

Unsupported structures.—This name Irving gives to the irregular masses of unreplaced country rock found in replacement ore bodies. They are not uncommon in the Monarch ore deposits. Several large blocks of quartzite were inclosed by the Madonna ores (Pl. XXII). Though these were in the fault zone they were completely surrounded by ore which evidently had replaced the rock that held the quartzite in place previous to ore deposition. Above No. 6 level of the same mine a block of limestone many feet across was nearly or quite surrounded by ore; this was near the fault but not in the fault. In the Lilly mine are found, within the ores, masses of black material containing a large proportion of calcium carbonate; this is evidently incompletely replaced limestone. The phenomenon of unsupported structures is shown on a microscopic scale in Plate XIX, the zinc blende and in a greater degree, the pyrite inclose minute grains of calcite or dolomite of the partly replaced rock.

A somewhat different phenomenon, though belonging to the same general class, is seen in a thin section of New York ore (Pl. XX). The specimen is composed of dominant zinc blende associated with subordinate diopside which is in large part automorphic toward the blende. Not only do the larger crystals of diopside with good crystal terminations penetrate the zinc blende, but the latter mineral incloses minute well formed crystals of diopside. Obviously these minute crystals, distant from other diopside, did not remain in place unsupported prior to the introduction of zinc blende. That diopside crystallized from a solution in zinc sulphide as it might from a rock magma is scarcely to be considered. There remains the probability that the zinc blende replaced some material, probably calcite, with which the diopside was associated prior to the deposition of zinc blende. In other specimens of diopside and diopsidic rock in this region calcite is the common associate of diopside, and it was probably calcite that was replaced by the zinc sulphide.

Form of ore bodies.—In most of the large bodies the ore lies in practically continuous shoots which follow the dip of the inclosing sedimentary rocks downward, but in most cases bear either to the right or left of the dip. This divergence from direction of dip is but few degrees in every instance noted, except in the Lilly mine. Here where the dip is nearly vertical, the longest shoot pitches north about 20°.

Cross-sections of some shoots are circular, but a greater number of shoots are elliptical in cross-section, having the longer axis parallel to the strike of the inclosing strata. Most of the shoots do not have a constant width and thickness, but pinch and swell. The swells may be lenslike or irregular in form, and connected by a workable body of pay ore or by an iron-stained joint- or bedding plane in the limestone. Two large ore bodies of the Madonna mine, but a few feet apart, were connected by an iron-stained joint-plane. Here also the large ore bodies, some distance from the main fault, were very irregular in outline.

Several of the deposits are tabular as a few in the Lilly, Garfield, and New York mines. Other replacement deposits occur in irregular or lenticular bunches or pockets, as in the Little Wonder mine and Wilson mine, but the longest diameter is generally parallel to the bedding of the limestone. As in the longer shoots, a series of bunches may be connected by an iron-stained joint- or bedding-plane. In some cases a seam of gouge connects two or more ore bodies, and here it is difficult to distinguish between the replacement type described and those deposits which are partly fault-fissure filling.

RELATION TO WALL ROCK

In a few mines the boundary between the ore and inclosing limestone is sharp, as in the Little Wonder mine. Generally, however, the ore near the border becomes increasingly calcareous until it passes by gradations into mineralized limestone. Where the galena has escaped oxidation it may sometimes be seen disseminated through the limestone near the ore. Though the sulphide ore of the Garfield mine shows an apparently sharp contact with the wall rock, specimens of the wall rock contain a considerable proportion of ore minerals. In general, the wall is merely the boundary of the ore that can be profitably mined.

FAULT-FISSURE FILLING

The largest ore bodies which have hitherto been mined in the district are of this type, as, for example, those of the Madonna and Eclipse mines. While there has been much local faulting in the vicinity of the Lilly mine, it is not definitely known that the Lilly ore bodies lie in fault fissures. It is probable that the main ore shoot of this mine was deposited along a fault-plane parallel to the bedding of the limestone.

The Madonna fault has forced the granite apart at least 15 to 24 inches where it passes into the granite from the limestone. The fissure between granite walls is filled with mineralized gouge on No. 6 level of the Madonna mine, but the space between the granite hanging wall and limestone foot wall farther northwest was filled with good ore. Much of the limestone here was replaced by ore, but replacement of the granite did not extend far. That there was a little replacement of the granite is indicated by the high silica content of the ore in contact with the granite.

On the higher levels of the Madonna there was much replacement of the limestone walls of the fault fissure and apparently not a little replacement of the quartzite where it was in contact with the ore. The same is true of the Eclipse ore shoots. The ore of the Hawkeye shoot in one place had replaced the limestone through a width of 66 feet. The essential difference between the two types described lies in the greater size of the second type owing probably to more favorable conditions for the circulation of mineral solutions.

FISSURE VEINS

In the two varieties of quartz monzonite and in the Etna quartz monzonite porphyry are a number of fissure veins which have a general northward strike and high dip. These veins are the fillings of pre-existing fissures that were for the most part probably caused by shrinkage of the rock near the top and sides of the intrusive bodies owing to cooling and crystallization. There is no observed evidence that the fissures were caused by faulting; the Mary Murphy vein in the Princeton quartz monzonite, northwest of Pomeroy Mountain, at a depth of 1,920 feet, has narrowed to a system of small veins which show no evidence of material shearing movement. It is probable that the vein minerals came from the still heated, but crystallizing rock magma, at greater depth.

The veins vary from a few inches to several feet in width. The Columbus vein is reported to be 6 to 20 feet wide.[1] The metallic minerals of the fissure veins of the Monarch district are chiefly, in variable proportion, galena, zinc blende, and pyrite; native silver was found in the Moose vein, and nearly all the sulphide ores carry silver values. The gangue is principally quartz. It is said that near the surface of the vein in the Michigan mine, solid galena filled the vein from wall to wall. In most places, however, where seen, the ratio of metallic minerals to quartz, in volume, is small. In most of the veins observed there is very little replacement of the wall rock. The ore which was being mined, in 1911, in a drift from the Pride of the West tunnel was really in a lode, about five feet wide, made up of several veins between which is mineralized rock. The veins vary in width from a millimeter to 20 inches. All the ore seen by the writer in prospects and mines in the areas mapped as

[1] See, in this chapter, the description of the Columbus mine.

quartz monzonite and quartz monzonite porphyry was in the veins here described, excepting a few deposits at contacts.

The quartz vein, north of Browns Creek, which carries molybdenite, pyrite, and white mica, may be closely related to pegmatite, but of this there is no observed evidence excepting the mineral associations. It is not improbable that the vein owes its origin to the granite intrusion a short distance east.

Perhaps with the fissure veins should be included the vein at the contact of pre-Cambrian granite with basic syenite, on the Mocking Bird claim. This vein, in 1911, had been followed by a tunnel 250 feet long. The vein varies from 1 to 10 inches in width. Quartz is the most abundant vein mineral—partly massive and partly in crystals projecting into small vugs. The vein carries numerous patches of good galena in addition to a little chalcopyrite and pyrite.

CONTACT DEPOSITS

Ores at or near eruptive contacts.—A few ore bodies occur at or near eruptive contacts where no evident contact metamorphism accompanied the deposition of ore. But little has been done to develop these deposits except in the Mason mine, near the crest of the range north of Vulcan Mountain. All of these ore bodies are very irregular in form and all, excepting possibly part of the Mason ores, seem to be pockety.

The Mason ores are at the contact between volcanic breccia and Paleozoic sediments which are slightly metamorphosed. It is probable, however, that the metamorphism was effected at the time of the intrusion of the quartz monzonite porphyry and prior to the deposition of the ore. The ores are chiefly silver-bearing oxides of manganese and iron, though a little galena and cerussite are present. The ores are in part without an appreciable quantity of rock material and in part form the matrix of a breccia of which the cemented fragments are chiefly materials from the volcanic breccia. This relationship indicates that, in part at least, the ores were deposited subsequently to the cooling of the volcanic rock.

On the Condor claim in Hunkydory Gulch a pocket or small shoot of good galena with a little zinc blende was found at the contact between the quartz monzonite porphyry and the Princeton quartz monzonite. Here there seems to be but little mineralization of the wall rock.

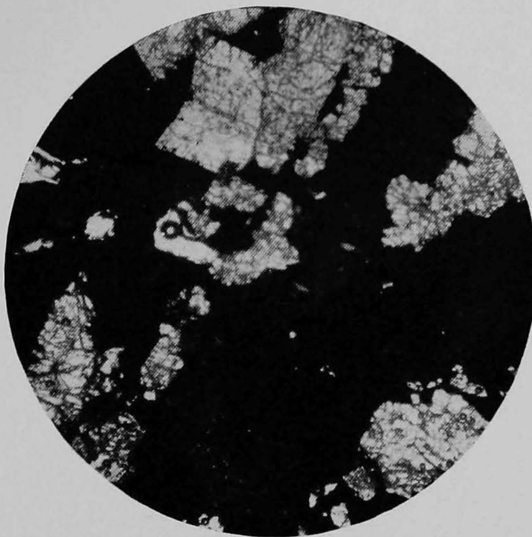
The ores of the Rainbow-Eagle Bird mine in Taylor Gulch replace crystalline dolomite just below a strong, westward-dipping porphyry dike. Whether these ores were deposited prior to or as a result of the porphyry intrusion is not known. The ore is very pockety and spotted. Unlike the average contact deposit it carries very high values in gold and silver. Both sulphide and oxide ores are found in the shallow workings. The sulphide is principally galena; the chief oxide is psilomelane. It is not improbable that these ores belong in the contact-metamorphic class, but thus far they have furnished no characteristic contact-metamorphic minerals.

Several pockets of silver-lead-copper ore were found in the Major and Shamrock mines at the contact between the "parting quartzite" and a porphyry dike.

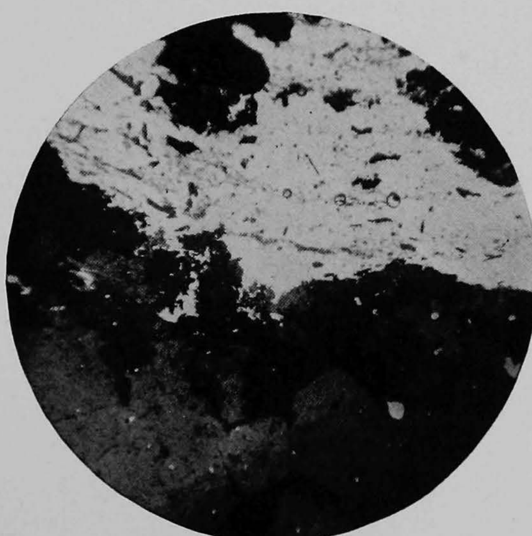
Contact-metamorphic ores.—About 130 feet east of the New York ore that is now being mined the mine tunnel crossed a small body of zinc ore. Though the upper part of the ore was oxidized, zinc blende associated with andradite and diopside was found at the bottom of the tunnel. The sulphide ore carries 45 per cent zinc and a little gold and silver. The diopside is pale green; the microscope shows it to be unaltered. The well-developed crystal outlines of the diopside indicate that it was formed prior to the deposition of zinc blende. (See Pl. XX, *A*.) It is not improbable that in the process of metamorphism any lime of the rock that did not become a constituent part of the diopside remained combined with carbon dioxide in the form of calcite, and that the calcite was replaced, soon afterward, by zinc blende. The oxidized ore toward the west does not carry any recognized characteristic contact-metamorphic mineral, but the rock nearby contains epidote, crystallized calcite, and a pale greenish-white micaceous mineral.

The high-grade silver ore of the Mountain Chief mine is said to have been associated with magnetite. At present a mass of magnetite a few feet across can be seen at the same stratigraphic horizon and a few yards south of the Mountain Chief tunnel.

Specimens of magnetite, epidote, and actinolite were found on the dumps on the Clinton claims east of Cree Camp, while almost the entire mass of sedimentary rocks on the hillside is metamorphosed. Diopsidic marble and epidote are the commonest metamorphic products. According to Mr. A. B. Brewington, who



A.—PHOTOMICROGRAPH OF ORE FROM NEW YORK MINE
The dark mineral is zinc blende; the light mineral is diopside. Ordinary light; x 14.



B.—PHOTOMICROGRAPH OF ORE FROM GARFIELD MINE
Dark gray mineral is pyrite; black minerals are galena and zinc blende; light mineral is chlorite. Ordinary light; x 14.

is familiar with all the Clinton ores, the best ore of this mine was associated with garnet.

For the sake of completeness a small deposit of possible contact-metamorphic origin is mentioned here. This is south of Greens Gulch, a short distance beyond the boundary of the mapped area, where pockets of galena have been found in the pre-Cambrian schist and gneiss associated with tremolite and a pale red garnet. Nearby is a mass of the conglomeratic schist described in the chapter on pre-Cambrian rocks. It is not improbable that there was considerable contact metamorphism in this vicinity prior to the regional metamorphism. The time of deposition of the ores is unknown; it may have been later than the period of regional metamorphism.

ORES ASSOCIATED WITH PEGMATITE, GNEISS, AND SCHIST

There has been no opportunity for a thorough examination of these minor deposits, and consequently their genetic relationships are in doubt. Nevertheless, the brief observations that have been made will be recorded here.

On the steep slope south of the river, at and west of Maysville, there is much pegmatite in the area mapped as gneiss. The pegmatite is composed mainly of quartz, with a little feldspar and white mica. Malachite, as a stain and as a thin coating, is very common on the quartz. In a few places chalcopyrite may be seen, in small quantity, in the quartz, filling fractures or in veinlets. North of the river a small quantity of good gold ore was shipped from a prospect in the pegmatite.

Much copper-stained pegmatite and gneiss are found, without the area mapped, about a mile south of the Bon Ton mine. Here there is also good galena associated with tremolite and a pale red garnet; this was mentioned in the previous section.

On the Highland claim, about half a mile south of the mouth of Como Gulch, much prospecting has been done in pegmatite. Here also, malachite is common. A specimen from one of the dumps shows bornite in small grains in mica-bearing quartz. The bornite is chiefly in small fractures in the quartz. On the same claim good galena was found in pegmatite. The vein from which the galena comes is said to be 3 to 18 inches wide.

Though the ore minerals mentioned are found with pegmatitic quartz it is not improbable that they are of later origin than the pegmatite. This is indicated by the partial or complete deposition of the copper minerals subsequent to fracturing of the quartz.

A small vein of zinc blende with chalcopyrite was opened on the Bon Ton claim, near the southeast corner of the area mapped. The wall rock is chiefly garnet-mica schist. While the ore appears to have been deposited in a fissure in the metamorphic rocks, the chalcopyrite is also disseminated through the wall rock either as a replacement or contemporaneous mineral.

A small shipment of gold ore was made from a shallow prospect in hornblende schist or gneiss about half a mile south of Shavano Mountain. However, it is possible that this ore was deposited from emanations from the nearby quartz monzonite or from solutions which got their metallic content from the quartz monzonite.

OXIDATION AND SECONDARY ENRICHMENT

With the possible exception of a few deposits in fissure veins all the known ore bodies are above the level of the ground water, and it is not known that secondary sulphides have been produced in quantity by any mine in the district. It is probable, however, that secondary sulphides were produced by the Columbus mine and possibly by the Michigan and Pride of the West mines many years ago. A few observations have been made which not only have a bearing on the original character of the ores, but also may form a basis for inference concerning future possibilities of the district, and it seems advisable to record them here.

There is no reason to doubt that the base metals of the ores were deposited almost entirely as sulphides. Evidences of this are seen in the bunches of residual galena that may occur in the oxidized ore at practically any depth, in the occurrence of pyrite —though rare—in and near limonitic ores, and in the sulphides of the Garfield mine. In nearly every mine that has produced lead, blocks of galena from a few inches to many feet in diameter have been found surrounded by oxidized ore. Galena is also found disseminated in the limestone near the replacement ore bodies. In the Little Wonder mine a pocket of galena was found only a few feet from the surface and was accompanied by very little lead carbonate.

Though galena is common on Monarch Hill, the more readily oxidized zinc blende is unknown and pyrite is very rare. When examination of the geology of the Madonna mine and surroundings was in progress in 1909, the writer was fortunate enough to see an instructive specimen that was furnished by Manager Burton, of the Madonna, immediately after it had been found by the miners who were stoping a body of limonitic ore. The specimen was a mass of limonite which contained the remains of a large number of small cubes of partly oxidized pyrite. Almost the entire body of several of the crystals had been removed by solution which had left five of the six faces of each cube intact, but supported by extremely thin and fragile walls. Within the box-shaped cavities thus formed, these thin walls still held a liquid which was probably a solution of iron sulphate. The process of oxidation was literally "caught in the act." With this exception, found 250 feet below No. 5 level, no pyrite was seen by the writer in the oxidized ores of Monarch Hill, and not any has been reported by the miners. However, on No. 6 level of the Madonna mine, pyrite and galena are found in the gouge of the fault fissure where both walls are granite.

The sulphides of the Garfield mine, in Taylor Gulch, include galena, zinc blende, pyrite, and pyrrhotite, and occur in a vein through a known length of 600 feet, where it is opened up about 300 feet below the surface. Oxidized ore overlies the sulphides a few feet higher and is also found on the same level some distance from the sulphides and in the same vein. These are evidences that this is a body of primary sulphide ore that has escaped oxidation; another good evidence is found in the presence of pyrrhotite among the sulphide minerals. So far as is known to the writer pyrrhotite has never been found as a secondary mineral in the zone of sulphide enrichment.[1] It is not impossible that oxidized ore will be found at a greater depth in the same vein.

In general, oxidation seems to have left the ores near the surface with low silver and gold values but with a high percentage of lead. That the original galena was richer in silver than the cerussite resulting from oxidation is indicated by the much higher silver values said to have been carried by the bunches of residual galena of the Silent Friend and Madonna mines. If any gold was present in the ores of the higher levels on Monarch Hill it was in too small quantity to be reported by the assayers and

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[1]See Lindgren, Waldemar, The relation of ore-deposition to physical conditions: Economic Geology, vol. 2, 1907, pp. 105-127.

Emmons, W. H., A genetic classification of minerals: Economic Geology, vol. 3, 1908, pp. 611-627.

smelters. No gold was found in the Eclipse ores until 1893, after the bulk of the known ore had been mined. Gold was not found in the Madonna mine above No. 4 level, and only a little was produced from above No. 5 level. A small quantity of gold was found in the Silent Friend ores that were near the granite. In all the ores produced prior to 1910 the gold content did not exceed a few hundredths ounces per ton.

The ore in the main Madonna shoot between levels 3 and 5—about 800 to 1,400 feet on the pitch—was comparatively lean in gold, silver, and lead, but contained a high percentage of iron. The same is true of the Eclipse ores in the same general position. Since patches of galena were found in this portion of the shoots and a little pyrite at a somewhat lower level, thus indicating that oxidation was not more active here than at a higher elevation, it is probable that the low content of lead is the result of original poverty of the ore in that metal.

At the lowest depth reached in the Madonna mine the high values mentioned in the section on tenor of the ores were found in a streak one to six inches wide. This streak is said to be very irregular in its course. In places it is comparatively flat; again it dips steeply. In general, it pitches with the main shoot, but keeps rather near the limestone—one to five feet distant. Samples examined show two varieties of ore in this streak. The first is well-crystallized cerussite with interstitial limonite; it carries about 10 ounces gold and 756 ounces silver per ton and 48 per cent lead. The second variety is a dark earthy or sooty material that carries about 65 ounces gold and 5,975 ounces silver per ton and 24 per cent lead. The silver of the second variety is largely in the form of cerargyrite, or silver chloride. Hot ammonia dissolves so much of this mineral from the ore that when the solution cools silver chloride is quickly precipitated as a scum on the surface of the saturated solution. Other constituents of this ore, determined after careful assortment under a strong lens, are: argentite in minute grains, cerussite in small crystals, a few minute grains of pyrite, and small prismatic crystals of quartz with good rhombohedral terminations. The solution of much iron in the ferric condition by hydrochloric acid, indicates that limonite is present in abundance. It is probable that part of the black material is galena; the sample runs well in lead and only a small amount of cerussite was detected. The condition of the gold was undetermined.

It is highly probable that a large part of the gold, silver, and lead of the high-grade ore at this level was precipitated from solutions that had moved downward through the oxidized and oxidizing ores. The fact that the highest-grade streak keeps near the limestone indicates that calcium carbonate was the principal precipitant. The pyrite may have been precipitated from descending solutions or it may be unoxidized pyrite of the original ore. The presence of much cerargyrite in the rich streak and of much pyrite in the original ore indicates that the ground water would be likely to carry both ferric chloride and ferric sulphate which could have effected the solution of gold[1]. The silver may have been carried by a ferric sulphate solution[2]; or it is not impossible that ammonia from the decay of animal organisms in the basal Ouray limestone at some time in the history of ore-alteration, may have more than neutralized the sulphuric acid in the ground water and carried the silver in the form of chloride. Though this is perhaps not probable, it is suggested by the strong bituminous odor that is emitted by the fossiliferous limestone when freshly broken. Doubtless even more organic matter was present before the limestone had been so long exposed to erosion.

In addition to this example of a streak of high-grade ore formed evidently by secondary processes, the ore of the Madonna mine from a point about 200 feet above No. 6 level downward shows a marked increase in gold and silver content over the ore of higher levels. The excess iron is about the same as in the ores of higher levels, the lead percentage is low, and zinc is absent. The vertical variation in the ore is shown in a general way in the table of production of the mine (p. 239). The ore of the higher levels ordinarily carried about 4 to 6 ounces silver per ton, 25 to 30 per cent lead, and no gold; the table shows no zinc for this part of the mine. Zinc ore is said by the old miners to be present on the higher levels, but during the eighties zinc ore was avoided. Below No. 3 level the silver values remained about the same, lead greatly decreased, but a little gold was found in part of the ore from No. 4 level downward. These conditions remained nearly constant down to 200 or 250 feet below No. 5 level, when the values in gold and silver greatly increased. The

[1]See Stokes, H. N., Experiments on the solution, transportation, and deposition of copper, silver, and gold: Economic Geology, vol. 1, 1906, pp. 644-651.

Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 491, 1911, p. 617.

[2]Stokes, Op. cit., p. 649.

Clarke, Op. cit., p. 620.

first line of the table for 1910 shows the character and amount of ore taken from the mine between 200 feet above No. 6 level and a few feet below No. 6. This shows that the year's tonnage carried an average of .44 ounces gold and 29.42 ounces silver per ton, but only 3.72 per cent lead. Iron continued in large excess over the silica. The second line for the year 1910 represents ore from levels 4 and 5; the output for 1911 was from levels 4, 5, and 6. The last two lines of the table therefore have no significance for a comparison of values at different elevations.

To summarize: The facts recorded for the ores of Monarch Hill seem to show that in the process of oxidation the ores of the higher levels lost a portion of their gold and silver content which was—in the case of the Madonna mine—deposited in part at a lower level still in the oxidized zone, and that the ores of the higher levels may have become richer in lead by the removal of much pyrite and possible zinc blende. The argentite, pyrite, and probable galena on the lowest level of the Madonna mine suggest proximity to an ore body of secondary sulphides.

The effect of oxidation in other parts of the district is but little known. The oxidized ores of the Garfield mine seem to be richer in both silver and lead than the sulphide ores, but the property has not been sufficiently developed to furnish a basis for a conclusion. Some of the oxidized ores of the Lilly mine have been very rich in copper in the form of cuprite; others are rich in lead. Good sulphide ores have been found in the Lilly mine, but no characteristic secondary minerals have been recognized in them. They are probably residual sulphides in the oxidized zone.

RANGE OF OXIDATION

In the Lilly, Eclipse, and Madonna mines oxidation of ores has reached a vertical depth of at least 800 feet below the surface, but this is only a fraction of the length of the ore shoots oxidized. The Lilly ore shoot has been oxidized through a pitch length of about 1,200 feet; oxidization of the Eclipse ores has a range on the pitch of 1,500 feet; while the pitch length of the Madonna oxidized ore shoot is about 2,000 feet.

In the glaciated areas oxidation has evidently extended but a few feet below the present surface. Just east of Boss Lake zinc blende, galena, and pyrite were found in dolomite within 10 feet of the surface, nothwithstanding the readily oxidizable character of zinc blende. Several prospects just east and northeast of the Lake expose bodies of iron sulphide, probably pyrite, which show no indication of oxidation at a depth of 10 feet. Near the head of North Fork fissure veins show galena, zinc blende, and pyrite within a few feet of the surface. It is reported that galena was found exposed at the surface in at least one vein.

Though this slight depth of oxidation in glaciated areas may be in part a result of structural conditions in the fissure veins, it can hardly be so considered in the case of the sulphides near Boss Lake. The areal range of the unoxidized sulphides in this vicinity is at least a quarter of a mile long and several hundred feet wide; this area, futhermore, contains no known metallic oxides in notable quantity excepting magnetite, which is in all probability a primary mineral. The occurrence of the sulphides in this vicinity with only superficial alteration is hence too general to be considered a chance immunity of the sulphides from oxidation. It is therefore inferred that by far the greater part of the oxidation of the ores of the district was effected prior to the time of glaciation of the Boss Lake locality.

AGE OF THE ORES

The contact deposits were probably formed at several different periods. Evidently the greater part, if not all, of the garnet and diopside in Taylor Gulch and at Cree Camp was formed at the time of the quartz monzonite intrusion, and it is probable that the ores with which these minerals are associated were deposited so soon afterward as to be considered practically contemporaneous. Part, if not all, of the ores in contact with the porphyry dikes of Taylor Gulch may have been deposited from emanations from the porphyry, but it is possible that the ores of the Mountain Chief and Rainbow-Eagle Bird mines are of the same age as the Clinton and New York ores which are evidently but little younger than the quartz monzonite. The ore at the contact between the Etna porphyry and quartz monzonite in Hunkydory Gulch is not older than the porphyry which is one of the comparatively late intrusions. It is probable that the ore of the Mason mine is not older than the volcanic breccia which is in turn evidently younger than the Etna property.

There is at hand no good evidence on which to base a conclusion as to the age of the ores in the pegmatite, gneiss, and schist, and at the contact between the basic syenite and granite.

The ores of the fissure veins were presumably deposited with the quartz in contraction fissures in the upper part of the igneous intrusions while the interior still retained much of its original heat. The ores of these veins in the two varieties of quartz monzonite may have been deposited synchronously, or at two not widely separated periods. The ore of the veins in the Etna porphyry, however, is as young as the porphyry, and hence probably much younger than the fissure-vein ores in the quartz monzonite.

Until mining developments are carried deeper all that can be positively said of the age of the ores of Monarch Hill, the Lilly and Garfield mines, and a few others, is that they were deposited after the folding and principal faulting of the sedimentary rocks in which they lie. The few fractures and faults seen in the ore bodies, are too slight to have been caused by the folding and faulting described in the chapter on structural geology. Knowing that Mr. Eilers had had opportunities, which do not now exist, to observe the relation of the largest deposits to the faulting, the writer asked him several questions, and received the following definite statements:

"The ore in the Madonna was all deposited, without the slightest doubt, subsequent to the faulting and folding. The ore showed no crushing or breaking in any part of the mine. There was never found any evidence of more than one period of ore deposition, which was subsequent to the faulting and prior to oxidation. The principal ore body in the Madonna down to the fourth level, was in the big fault itself, but small branches went out for some distance to the southwest and northeast into the limestone strata, generally following the planes of stratification to the southwest, and being very irregular in the broken ground to the northeast of the fault. The ore bodies themselves were never faulted anywhere in the mine".

Since Mr. Eilers wrote the above, ore was discovered in the Madonna fault at a much lower level, No. 6. Examination of this occurrence confirms every statement made by Mr. Eilers in regard to the relationship between ore deposition and faulting. The replacement deposits and fault-fissure fillings are therefore post-Paleozoic in age. They are probably not older than the quartz monzonite, and are hence probably of early Tertiary age. Certainly they were deposited early enough to permit nearly all of the vast amount of oxidation that has taken place before glaciation of the region. In the history of the ores the time that has passed since the region was glaciated is insignificant.

GENESIS OF THE ORES

The association of ores with characteristic contact-metamorphic minerals in a few ore bodies and the occurrence of ores in contact with dikes, seem to indicate that the metals of the contact deposits, described on preceding pages, emanated from the intrusive rocks or rock magmas. Most of the contact-metamorphic minerals evidently owe their formation to the intrusion of quartz monzonite, and the same intrusion may be suspected of furnishing the metals of the contact-metaphoric ore bodies. It is possible that the ores in contact with the dikes were derived from the dikes.

The largest known ore bodies of the district are replacements, and fault-fissure fillings, removed a considerable distance from an eruptive contact and not known to be associated with minerals of contact-metamorphic origin. Conclusive proof of their origin is lacking at the present time. Nevertheless, reasonably safe inference may be drawn from facts obtained in the field. These facts may be grouped as (1) mineral composition of the ores, (2) structural relationships of rocks and ore bodies, and (3) distribution of ore minerals.

Although sulphides of copper, iron, lead, and zinc are present in deposits of other origin they are common minerals in ores which are generally conceded to have been deposited from ascending hot solutions. All but pyrrhotite may be neglected in framing a hypothesis except perhaps where they may be significant in the comparison of ores of different parts of the district and of different types of deposits. Gold and silver are important constituents of the Monarch Hill ores. These are not common metals in ore bodies which owe their origin to the work of cold ground waters. The specular hematite on and east of Monarch Hill and the pyrrhotite of the ores in the Garfield mine indicate contact-metamorphic deposits or deep-vein deposits[1]. On Monarch Hill even much of the limestone near the ores shows, in thin section, only incipient crystallization of calcite with no other mineral. Much of the dolomitic limestone is crystalline, but not more crystalline than might result from dolomitization.

[1]Lindgren, Waldemar, Economic Geology, vol. 2, p. 125.
Emmons, W. H., Economic Geology, vol. 3, p. 621.

In the ordinary use of the term, therefore, the ores of Monarch Hill can scarcely be considered contact-metamorphic deposits. Yet there is so striking a similarity between the ores of Monarch Hill and the contact deposits of Taylor Gulch and Cree Camp that a common source is suggested. The ores of the Lilly and Garfield mines of Taylor Gulch in their structural relationships have much in common with both types. Epidote and garnet are common on the surface a few hundred feet north of the breast of the Lilly mine while a small quantity of chlorite occurs with the Garfield ore. But the shape and continuity of these ore bodies and their relation to apparent faulting are similar to those of ore bodies on Monarch Hill.

Though the general northward to northwestward pitch of the ore shoots is in large part due to the structure it indicates that the mineral-bearing solutions moved in a common direction. In so far as the folding and faulting in the vicinity of the Clinton, Lilly, Alaska, Bonnie Belle, and Ben Hill mines are concerned the ore shoots of those mines might be vertical or pitch south as well as north, yet all pitch toward the north. This uniformity is too general and displayed over too wide an area to be considered a mere coincidence.

Galena, pyrite, and zinc blende carrying good silver values and a little gold have been found in patches west of Monarch in the Lake fault. The same sulphides with less gold and silver occur near the same fault at Boss Lake. Samples from these localities carry all the metals found on Monarch Hill except copper and molybdenum, and all the known primary metallic minerals except hematite. Instead of hematite, magnetite, which is formed under similar conditions, is found at Boss Lake. North of the lake and but a few hundred feet south of the quartz monzonite, oxidized silver-lead ore is found in the Lake fault. Therefore, with the exception of less than a mile on the slopes of Syncline Hill where the fault is covered and unprospected, and a short interval at the creek where the fault is covered by a morainal deposit, the characteristic metals and ore minerals have been traced from the quartz monzonite, north of Boss Lake, to the top of Monarch Hill.

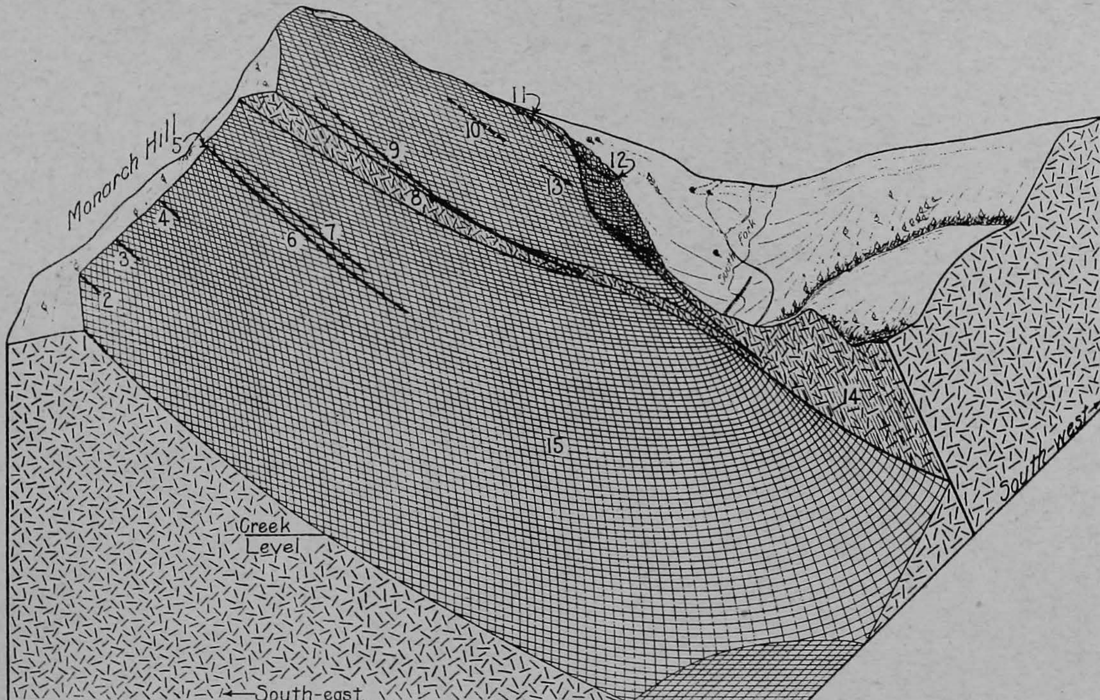
A short distance west of the fault, in the granite near the quartz monzonite, several thin seams, said to carry high values in gold and silver, have been found. In the Tomichi district the granite is commonly mineralized near the quartz monzonite and at least two veins have produced payable ore. Ore-bearing fissure veins are common in the quartz monzonite in the Chalk Creek and Tomichi districts and are also present in the Monarch district.

From the facts mentioned it seems reasonable to infer that the quartz monzonite magma held in solution metals, of which part was carried by ascending hot solutions through the sedimentary rocks and deposited as fault-fissure fillings and replacements, and part was carried by hot solutions into the fissures of the surface crust of the batholith and was deposited with quartz and other gangue minerals as fissure-vein fillings. It is not improbable that the deposition of the ores outside of the batholith was, in part, slightly in advance of the deposition in fissure veins which required the crystallization of the magma to a depth of several thousand feet before fissuring was complete. (The Mary Murphy filled fissure extends at least 1,920 feet below the present eroded surface.) Meteoric waters may have had a small part in transporting the ore minerals. However, when the size of the batholith is considered it seems probable that the total volume of magmatic water that must have been given off, was great. Naturally a convenient outlet like the Lake fault, might be expected to lead off a large share of this water.

This hypothesis for the source of the ores of Monarch Hill necessarily ascribes to the solvent, power to carry the minerals through a vertical range of several thousand feet against gravity and a horizontal range of two and one-half miles—unless the quartz monzonite contact dips southward under the sediments. This is a wide range, but it does not seem too great when it is considered that marble has formed a mile and a half from the visible contact and cordierite hornfels more than a mile away in this direction, that the displacement of the fault is over 4,000 feet, that the readily soluble limestone was much broken, and that the batholith probably has now an exposed surface of 200 square miles or more. Figure 10 is intended to show the structural relations that existed between the faults and the synclinal fold which would make this locality peculiarly receptive.

DEPTH AT WHICH THE ORES WERE DEPOSITED

The Paleozoic sediments of Taylor Gulch and North Fork, which were crosscut by the quartz monzonite, have a thickness of at least one mile and probably 7,000 feet. The latter is the



LEGEND

1. Evening Star ore shoot.
2. Contact ore shoot.
3. Delaware ore shoot.
4. April Fool ore shoot.
5. Mayflower fault.
6. Eclipse ore shoot just above granite.
7. Eclipse ore shoot just below quartzite.
8. Madonna fault.
9. Madonna ore shoot.
10. Silent Friend ore shoot (position estimated).
11. Silent Friend ore shoot.
12. Hawkeye ore shoot.
13. Hawkeye ore shoot.
14. Lake fault.
15. Contact between granite and limestone.

Figure 10.—Stereogram of Monarch Hill and vicinity of Monarch. The position of intersection of the Lake fault and Madonna fault is hypothetical, as is also the shading of the Lake fault into the overturned fold between 12 and 13.

true thickness if the apparent thickness is not partly due to faulting of which there is no known evidence. The thickness of the original cover of the batholith was probably at least as thick as the Paleozoic sediments. If the ores emanated from the freshly-intruded quartz monzonite those at the highest elevation on Monarch Hill and in Taylor Gulch were therefore probably deposited at a depth of at least 7,000 feet, and the ores near the creek level at a depth between 8,000 and 9,000 feet. This makes no allowance for a probable greater thickness of Paleozoic sediments and for possible Mesozoic sediments.

PRACTICAL INFERENCES AND SUGGESTIONS FOR FURTHER DEVELOPMENT

As a result of detailed study of the structure of the Monarch district and of the relation of the known ore bodies to structure, opinions of the future possibilities of the district are inevitably formed. As an agent of the Survey, it is the writer's duty, while pleading fallibility, to give frank expression to those opinions that may be supported by valid reasons if they may in any measure contribute to the economic development of the district. The day of the "sure thing" in mining is past, but there are geological reasons for the belief that the possibilities of the Monarch district are far from exhausted. It is intended to mention a few of these reasons in the following paragraphs and to point out a few localities that would seem to merit thorough prospecting.

The lowest depth at which metallic minerals may be precipitated from solution is governed by so many factors that it is impossible to state positively, in advance of development, just what that depth is in any particular region. If the hypothesis advanced for the genesis of the Monarch Hill ores is tenable—and the writer believes it is—there naturally arises the question, How far do the ores go down toward the north in the Lake fault?

It has already been demonstrated in the Madonna mine that the ores were precipitated through a vertical range of nearly 1,500 feet. These ores were probably deposited at a depth of not less than 7,000 to 9,000 feet below the surface. It is hence not improbable that under similar structural conditions ore minerals could be precipitated a few hundred feet, or even a thousand feet deeper. This would be only a fraction of the known range of deposition in this area and only a small fraction of the distance from the surface. The structural conditions along the

Lake fault where it cuts off one limb of the syncline are similar to the conditions on No. 6 level of the Madonna mine, namely, a granite hanging wall and a footwall of limestone overlying granite. It is probable, however, that at this greater depth the limestone is less fractured than it is in the Madonna mine. The chief differences to be considered are of temperature and pressure; a great increase of temperature and pressure would be unfavorable to precipitation of ore minerals. As shown by the contact metamorphism the temperature along this fault was high. But it is probable that solutions that got their metallic content from the quartz monzonite continued to circulate long after the surface crust of the batholith as well as the surrounding rocks had cooled to a much lower temperature. It is unlikely that the temperature in this fault was higher than that of the quartz monzonite itself at a depth of nearly 2,000 feet below the position of the present eroded surface, at the time the metallic sulphides of the Mary Murphy mine were deposited. It is also unlikely that the pressure in the Mary Murphy vein at the same depth was less than that in the Lake fault. While the Mary Murphy vein is not known to carry sulphides in sufficient quantity, at this depth, to be useful as ore, the small amount is probably due in large part to structural conditions—that is, to the narrowness of the vein. Favorable to greater precipitation in or near the Lake fault is the readily replaceable limestone of the footwall. It is scarcely to be expected that primary ores at great depth will be found in such large bodies as were deposited at a higher elevation or with the same metallic content.

It should be mentioned here that geologists have not ordinarily found gouge-filled fault fissures of great displacement favorable to ore deposition. To quote Ransome[1]:

> Great fault fissures are rarely filled by veins, perhaps chiefly because great movement tends to pack the fissure tightly with compressed impervious attrition material, and if ore is deposited at all it is likely to be crushed and dispersed through the gouge by the recurrent movements characteristic of great dislocations. On the other hand, productive veins often accompany great faults and fill the minor associated fissures.

Nevertheless, on No. 6 level of the Madonna mine ore filled the fissure completely, for many feet, between the granite hanging wall and limestone footwall and replaced much of the lime-

[1]Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: Prof. Paper U. S. Geol. Survey No. 75, 1911, p. 125.

stone. The quantity of gouge between granite walls farther southeast indicates that the fissure was probably continuously filled with gouge prior to mineralization, where it extended into the limestone. Fracturing of limestone adjacent to the original gouge may have permitted the first circulation of mineral-bearing solutions which effected replacement of both gouge and limestone. Though there is much apparently impervious gouge in the Lake fault where it is opened by the Monarch Contact tunnel, small patches that assay well in silver are found in the fractured limestone not far from the fault. The existence or non-existence of payable ore in the fault at greater depth could probably be most economically determined by prospecting with a diamond drill.

A position in the Lake fault, which should not be overlooked in prospecting is at or near the intersection of the fault with the "parting quartzite". The quartzite, as might have been expected, has been shown to be a good aquifer for ground water near the surface, in the drift along it, in the Monarch Contact mine workings. Here enough water issues from the quartzite to keep the drift wet and even to form a small stream. The quartzite should have been as good an aquifer for ascending mineral-bearing solutions at the time the ore bodies were formed. If the sheared ends of the quartzite strata were in the path of mineral-bearing solutions at depth there is no apparent reason why the latter should not in part have ascended along the quartzite and deposited their metallic content in the limestone above or below the quartzite wherever pressure and temperature were favorable to precipitation. In the Eclipse mine an ore shoot, developed through a length of 1,200 feet, immediately underlies the same quartzite.

An effort has been made to calculate the probable depth of the limestone of the fold west of the Lake fault and southwest of Monarch, but no dependably accurate results have been obtained. The surface is largely covered by morainal material and mine developments are few. Furthermore, the dip and strike are known to change greatly within short distances. The only data, having a bearing on the depth of the limestone, that can be obtained, at present, under ground, are: the distance between the positions of the "parting quartzite" on opposite limbs of the syncline, in the Madonna No. 6 tunnel, and the absence of the same quartzite from the crosscut in the Hawkeye mine. (See p. 243.)

Ordinarily, the thickness of the limestone below the quartzite is 200 to 250 feet. Since the Hawkeye crosscut passes under the quartzite and the distance from the granite west of the fold to the granite of the east limb is 400 feet, it is evident that the distance from the crosscut to the bottom of the fold in a line at right angles to the pitch of the fold is probably not more than 200 feet. The vertical distance from the crosscut to the bottom of the fold is greater than the distance in the line first taken. If there has been faulting parallel to the axial plane these figures have no value. West of the Madonna fault, in No. 6 tunnel, the horizontal distance from the quartzite on the west limb of the fold to the same quartzite on the east limb is about 1,000 feet. At right angles to the strike the horizontal distance is about 900 feet. The average dip of both limbs, which are nearly parallel, is perhaps about 60°. It is possible, though not probable, that the quartzite at the lowest point is below the tunnel level a distance less than one-half that between the quartzite on opposite limbs of the fold. More probably it is deeper and is hence very likely at least 400 feet below the tunnel level. Add to this 250 feet, the approximate thickness of the quartzite and lower limestone, and the greatest depth below the tunnel level at which limestone may be expected is not less than 650 feet. East of the fault the limestone should extend to a greater depth than on the west. Uniformity in ascent of the bottom of the fold from this point to the Hawkeye crosscut is probably interrupted by faulting. If this part of the fold was not below the range favorable for the precipitation of ore minerals there is still much undeveloped ground in which primary ores may have been deposited. If ores can be shown to exist in or near the Lake fault at considerable depth, they may reasonably be expected in the fold wherever structural conditions are favorable.

A few localities within this part of the field, because of their apparent favorable position will be specifically mentioned. There is no known convincing evidence that the Lake fault extends as far south as the Hawkeye fault. More probably it shades into the overturned fold between the Hawkeye and Madonna faults as represented in figure 10. If the Lake fault does intersect the Hawkeye fault the Hawkeye and Silent Friend ores may have been deposited from solutions that passed directly from the Lake fault into the Hawkeye fault. On the other hand, if the Hawkeye and Lake faults do not intersect—and it is probable that they do not—the apparently most favorable channel for ascending solutions would be at the bottom of the syncline where sharp folding must have caused a tendency to fracture. If the mineral-bearing solutions did ascend along this fold it is reasonably certain that part of the metallic content was precipitated at the bottom of the syncline before the solutions reached the position of the known ore shoots.

The plan of the Madonna mine (Pl. XXI, in pocket) shows that the main ore body from Zero level to the third intermediate level lies in a slightly curved zone which, produced, passes west of the portal of No. 6 tunnel. A small ore body was found in the same zone on No. 4 level. Between levels 4 and 5 the ore was mainly out of this general course and irregularly distributed. On No. 6 level a large body was found in a strong fault about 200 feet northeast of the position mentioned. This body was continuous with the main deposit on No. 5 level. The fault in which it lay dips southwest, though steeply. From these facts it seems possible that the Madonna fault forks near No. 4 level. Surface indications of a fault about 200 feet southwest of the known fault on No. 6 level are a spring which issues from the limestone west of the No. 6 dump and the straight sharp gully on the steep slope west of the portal of No. 4 tunnel. The existence or non-existence of a fault in this position should be determined.

The Mayflower is a strong fault and evidently in it the two large ore shoots of the Eclipse mine were deposited. This fault should be investigated at a greater depth.

Whether or not the Mayflower fault and the bottom of the syncline carry undiscovered oxidized ore above the level of the ground water, they, together with the Madonna fault, or faults, may be expected to be, below the ground-water level, the loci of secondary sulphide-ore bodies. The length of the two known shoots of oxidized ore of the Eclipse mine is 1,200 feet each. Recently another ore body has been opened on what is probably the same fault at a depth 300 feet, on the pitch, below the bottom of the lower shoot shown in figure 13. The known oxidized ores of the Madonna mine have a range of nearly 2,000 feet. The aggregate length of the known main shoots of oxidized ore of the Hawkeye and Silent Friend mines is not less than 1,600 feet. This figure would be greatly increased if the lengths of the smaller shoots were added. It is probable also that much of the main shoot of the Hawkeye mine is undeveloped, and hence not included in the estimate. The character of the oxidation, in so far as it has been determined, was described in the section on oxidation of the ore bodies. The evidence is strong that much zinc, gold, and silver, some lead, and perhaps a little copper have been removed. If the amount of oxidation is a measure of the volume of secondary sulphides that may be expected below the level of the ground water, the prosperity of the district is assured for several years to come. It is possible that in those shoots whose walls are both limestone the oxidized ore minerals were largely precipitated before they reached the present level of the ground water. It is not improbable, however, that a considerable part of the oxidized minerals in such shoots and a large proportion of the oxidized minerals in the shoots in contact with at least one granite wall, reached the level of the ground water before they were precipitated.

There is a possibility that descending solutions have found their way into the fissures in the granite below the ore shoots, and this possibility should not be overlooked in prospecting. More probably, however, the descending solutions chiefly found their way to a lower part of the syncline. This is indicated by the stream-laid sand in old water courses in the Madonna and Silent Friend mines.

It cannot be said that the possibilities of Monarch Hill are exhausted until after the granite-limestone contact has been thoroughly prospected. The known ore shoots, except the Black Tiger shoot, are represented in figure 10. It is not known that any one of these has completely failed at the lowest depth reached. Work on several was suspended because of the expense of hoisting the comparatively low-grade ore, and packing it on burros to the railroad. By a consolidation of interests and working many claims through a single tunnel these properties might be put on a paying basis. Such a tunnel would encounter any possible ore bodies near the granite. Evidence that blind leads may be discovered is shown by developments in the Madonna mine where a large body of low-grade iron ore in a probable fault zone was encountered about 200 feet east of the main fault on No. 6 level. No indications of the fault or ore have been found at the surface.

To prospect the granite-limestone contact from the Black Tiger to the Eclipse in the oxidized zone would require a tunnel about a mile long. If it should be demonstrated that large ore bodies exist near Monarch below the level of the ground water, of which there will doubtless be a large flow, it may be found economical to prospect this contact by a tunnel which could be used also for drainage. Such a tunnel, having a length of about 9,000 feet, would drain the area near Monarch to a depth of about 600 feet below the level of the creek.

The faulted ground at the head of Taylor Gulch and west of the head of the gulch should be carefully examined. Many shallow mines have produced good ore, but no deep prospecting has been done except in the Jewell tunnel.

On the east side of Taylor Gulch there has been much oxidation of the ores, though perhaps less than on Monarch Hill. A considerable part of this ore is in contact with quartzite, granite, or porphyry. Where this is the case, if not also where the ore is completely inclosed by limestone, it may be expected that at least part of the zinc and silver has been carried to a lower level to be precipitated as secondary sulphides.

The moraine-covered synclinal fold southeast of Cree Camp would appear to be promising ground, notwithstanding synclines are generally considered unfavorable for ore deposition from ascending solutions. However, there was probably considerable fracturing of the limestone in this sharp fold. The valley that has been formed by erosion is evidence that the rock here was less resistant than the rock on both sides. Fractured and readily replaceable limestone dipping toward the border of a large body of intrusive rock should form a favorable outlet for any possible metallic emanations. A shaft sunk through the moraine into the limestone a short distance above the granite, and a few crosscuts in addition, if necessary, would cost a comparatively small amount, and should demonstrate the presence or absence of an ore body. The ore bodies of the Garfield, Lilly, and Clinton mines are on the same contact and not far distant.

Although large contact deposits have been mined in a number of districts, in general this type tends to be bunchy. In regard to the persistence of the contact deposits of the Monarch district, only one thing is known, namely, that the contact itself goes down. Of contact deposits Lindgren[1] says:

Although cases may be easily conceived in which the deposits would continue in depth and length for several thousand feet it is far more com-

[1]Lindgren, Waldemar, Ore deposits and deep mining, Economic Geology, vol. 1, 1905, p. 37.

mon to find them irregular and spotted in their mineralization, so that while there is no genetic reason why they should not be continuous to the greatest depth attainable by mining they will as a matter of fact often give out when least expected. Owing to the irregular surface of contact, the finding of the continuation of lost ore bodies is often very difficult. Slight changes of composition and texture of the rocks influence their susceptibility to contact metamorphism to a very surprising degree. Few mines on contact deposits have been worked at a greater depth than a few hundred feet. Oxidizing surface waters may greatly enrich contact deposits of poor grade by the development of oxidized ores; this especially refers to copper deposits although such oxidized ores rarely extend downward more than a few hundred feet at most and this only in very dry climates.

Nevertheless, indications at the surface and in the shallow workings of the mines of the Monarch district in which contact deposits are found, fully justify a moderate outlay in development work.

It is not improbable that many fissure veins carry ore in sufficient quantity to be profitably mined if a concentrating mill were built within easy reach of the mines. The streams carry abundant water, at least during the summer, for milling purposes. Surface openings are so numerous in the fissure veins that, with a small expense for removal of waste, many of the veins could be systematically sampled. It is probable that in the glaciated areas the ore minerals near the surface are almost exclusively primary sulphides and that values will change but little with increasing depth as far down as the veins carry ore bodies of workable size. In the unglaciated areas a change in value may be expected with increasing depth. The quartz in these veins near the surface may be nearly barren, as in the Moose vein. Yet the Moose vein has produced high-grade ore at a depth of a few feet.

DESCRIPTIONS OF MINES

Many of the mines which were formerly producers have been idle for a number of years. The ore bodies and stopes of these were inaccessible to the field party because of their caved condition or bad air, or both. This also applies to the earlier workings of the large mines operating at the present time.

A few mines have been worked through vertical shafts, a number through inclines, but by far the greatest part of the ore mined has been hauled out through tunnels. Electric power is supplied by the Salida Light, Power & Utility Company whose plant is near Maysville.

No timbering is required in many places where the tunnels pass through barren rock, but the walls are generally not self-supporting adjacent to the ore bodies. Here square sets are commonly used both in the drifts and in the larger stopes. A few of the smaller stopes are stulled but many of the larger ones are several sets high and many sets wide.

For convenience the mines are considered in groups of the following localities: Monarch Hill, Taylor Gulch, Cree Camp, Middle Fork and tributaries, and North Fork and Browns Gulch. A summary of the geology of these areas was given in Chapter VII. Following these groups are brief descriptions of a few miscellaneous small mines and prospects outside of the areas named.

MINES OF MONARCH HILL

The mines of Monarch Hill which have produced ore since the Survey party began work in the district, in 1909, are the Madonna, Hawkeye, Silent Friend-Fairview, Wilson, Eclipse, Oshkosh, and Little Wonder.

MADONNA MINE

History.—Soon after the discovery of the Madonna mine, by Smith and Gray, it was sold to a company of New York and Iowa men who erected a small smelter at the foot of the hill for the purpose of smelting the ores of their mine. Partly because of the lack of siliceous ores that were needed to flux the basic Madonna ores and partly because of the high cost of coke which had to be hauled 20 miles by wagon, the smelter was not a success. The ore which the Madonna was then producing was of too low grade to pay for the long haul to the railway at Maysville, and consequently the output was small before the mine was purchased by A. Eilers and his associates in 1883. From that time until the nineties, the mine was worked, under the management of Mr. Eilers, by the Colorado Smelting Company which included the former operators.

From 1883 to 1894 production was continuous. Since 1894 the mine has been closed for short intervals, but ore has been produced every year. Various leasers have operated the mine for over 15 years. In 1908 the mine was leased to the Monarch-Madonna Mining Company, which, under the management of K. E. Burton, has operated the mine to the present time.

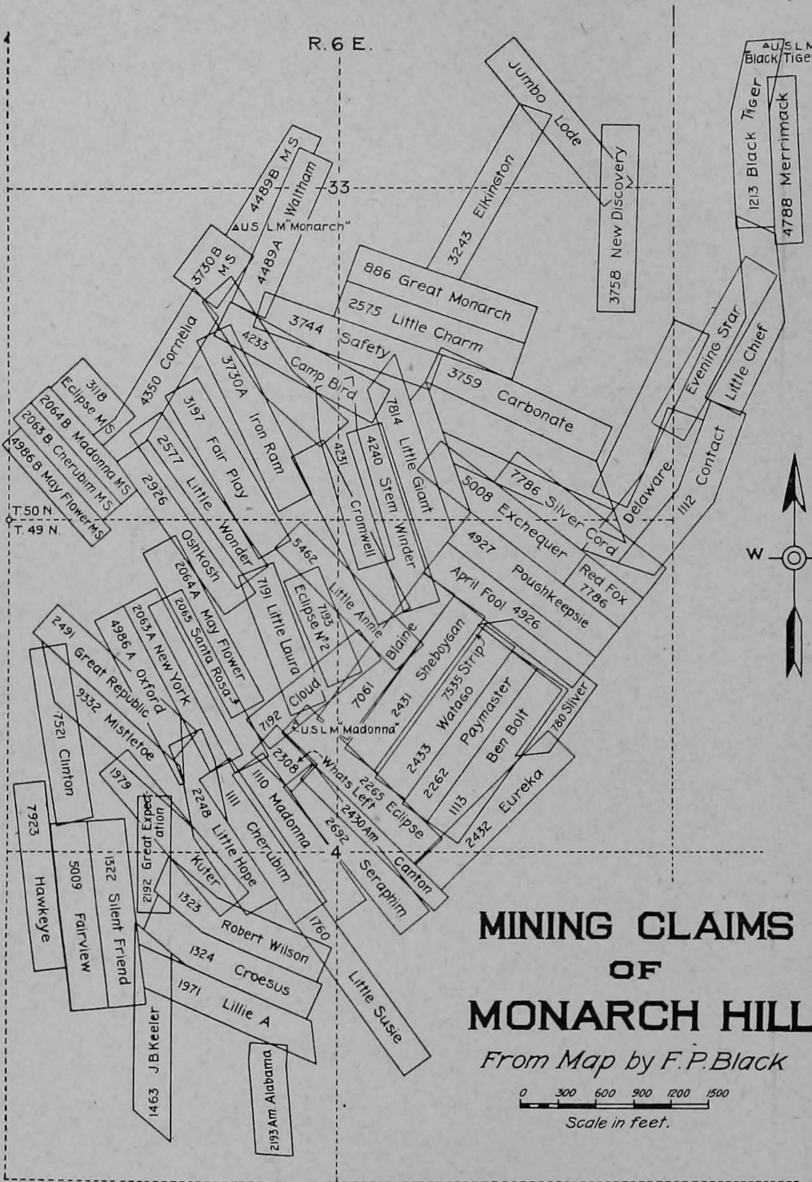

MINING CLAIMS
OF
MONARCH HILL
From Map by F. P. Black
0 300 600 900 1200 1500
Scale in feet.
R. 6 E.
33
4
T. 50 N.
T. 49 N.
W
E
Jumbo Lode
3243 Elkinston
3758 New Discovery
U.S.L.M. Black Tiger
1213 Black Tiger
4788 Merrimack
4489B M.S.
Waltham
U.S. L.M. "Monarch"
4489A
3730B M.S.
886 Great Monarch
2575 Little Charm
3744 Safety
4233
Camp Bird
3759 Carbonate
Evening Star
Little Chief
4350 Cornelia
3118 Eclipse M.S.
2064B Madonna M.S.
2063B Cherubim M.S.
4986B May Flower M.S.
3730A Iron Ram
3197 Fair Play
2577 Little Wonder
2926 Oshkosh
4231 Cromwell
4240 Stem Winder
7814 Little Giant
5008 Exchequer
7786 Silver Cord
Delaware
1112 Contact
4927 Poughkeepsie
Red Fox 7786
April Fool 4926
2064A May Flower
2065 Santa Rosa
2063A New York
4986A Oxford
2491 Great Republic
9332 Mistletoe
7521 Clinton
5462 Little Annie
7191 Little Laura
7193 Eclipse No. 2
Blaine
Sheboygan
7535 Strip
2431 Watago
Paymaster
Ben Bolt
780 Silver
7061
Cloud
7192
U.S.L.M. "Madonna"
2308
Whats Left
2265 Eclipse
2430 Am.
2433
2262
1113
Eureka
2432
Canton
2692 Seraphim
1110 Madonna
1111 Cherubim
2248 Little Hope
Kuter
1979
2192 Great Expectation
1322 Silent Friend
5009 Fairview
7923 Hawkeye
1323 Robert Wilson
1324 Croesus
1971 Lillie A
1760 Little Susie
1463 J.B. Keeler
2193 Am. Alabama

Figure 11.

Soon after the lease was secured, while the lower-grade ores of levels 4 and 5 were being mined, a tunnel was driven about 1,500 feet in the limestone, about 450 feet below No. 5 level, with the intention of opening the ore shoot at greater depth. In January, 1910, in a crosscut from this tunnel—No. 6—a large ore body of higher grade than had formerly been found in the mine, was encountered. From the time of dis covery of ore on this level until the winter of 1910-11 ore was continuously shipped from No. 6 level by the Monarch-Madonna Mining Company while sub-lessees were taking ore from higher levels. In 1910 the output of the mine was the greatest of any year since 1889.

Further to develop the mine the sinking of a winze began late in 1910 and continued successfully to a depth of about 100 feet in dry ground. The heavy flow of water, however, in the winze, when the melting of the winter snow began, forced the installation of a pump. This pump was of too small capacity to handle the water, and work in the winze was consequently suspended until December, 1911, when, the water having lowered, work was resumed, and the winze sunk to a depth of 155 feet below the tunnel level. A pump with a capacity of 500 gallons a minute was ordered for delivery April 1. The factory failed to make the delivery promptly and a pump with a capacity of 160 gallons a minute for a depth of 500 feet was installed. This was inadequate, but by supplementing it with a bucket it was possible to run levels at 100 and 150 feet below the tunnel level and to ship much high-grade ore. Late in July the single over-taxed pump broke, and work was temporarily abandoned below No. 6 level. During the remainder of the year shipments continued from the upper levels.

Production.—The Madonna mine has produced about $4,900,000 worth of ore. Mr. Eilers has generously compiled a table, from figures taken from the books of the Colorado Smelting Company, which shows the output of the mine by years from 1884 to 1909. This table, to which have been added the figures for 1910 and 1911, kindly furnished by Mr. Burton is shown on page 239, with modifications. Short tons are substituted for pounds given by Mr. Eilers and gross values take the place of net proceeds. The percentage of lead and zinc, and the ounces per ton of gold and silver are based on net weight—that is, the gross weight less moisture. The average commercial value in New York, for each year, is given for silver, lead, copper, and zinc. The coinage value of gold is given. At the time of writing the figures for 1912 have not been compiled; but in view of the high grade ore shipped from the lowest levels in the early summer as well as the lower-grade ore from the upper levels throughout the year, it is probable that the production has been sufficient to bring the total output up to $4,900,000. This does not take into consideration the small amount produced by the former owners.

Development and equipment.—The Madonna has been worked through seven tunnels (Nos. 0 to 6). These tunnels are all connected by winzes and stopes; drifts and crosscuts have been run on intermediate levels. The vertical distance from the surface above Zero level to the bottom of the winze sunk from No. 6 level, is about 1,475 feet.

The mine is equipped with electric lights, electric hoist, and an electric drill which is used only in development work. It is proposed to install a steam plant and generator to supply power for pumping during the emergencies that arise when the current supplied by the Salida Light, Power & Utility Company is temporarily cut off. A gravity tramway connects the ore-house at the railway siding with the higher levels. The ore from No. 6 level is hauled by wagon a few hundred feet to the railway siding.

Geological features.—The writer has seen the ore bodies and stopes on No. 6 level and 120 feet upward, and from 100 feet above to 150 feet below No. 5 level. The winze on No. 6 was filled with water when the mine was visited in 1911, and filled to the 100-foot level below No. 6 when the mine was visited in 1912, twenty-four hours after pumping had stopped. With this explanation the reader can readily judge how much here recorded is the result of personal observation. Notes concerning the upper levels and the levels below No. 6 have been furnished by Messrs. Eilers and Burton and the mine superintendents.

The largest ore shoot lies in and near the Madonna fault which was described in the chapter on structural geology, but other payable ore bodies were found between this and the Mayflower fault. Many branches extend from the main shoot into the limestone on each side of the fault. These branches are said to follow the stratification planes on the southwest, but to be more irregular in the broken ground on the northeast side of

Production of the Madonna Mine

Year	Gross Weight Short Tons	Per Cent. Moisture	GOLD Fine Ounces	GOLD Ozs. Per Ton	GOLD Value	SILVER Fine Ounces	SILVER Ozs. Per Ton	SILVER Value	LEAD Pounds	LEAD Per Cent.	LEAD Value	COPPER Lbs.	COPPER Value	ZINC Pounds	ZINC Per Cent.	ZINC Value	GROSS VALUE
1883 Incl. Jan'84	8,160	13.70	....	......	....	44,117.87	6.26	$ 48,970.84	4,242,944	30.13	$ 182,022.30	....	....	....	......	....	$ 230,993.14
1884	18,822	13.52	....	......	....	97,252.11	5.97	108,241.60	10,195,244	31.32	380,282.60	....	....	....	......	....	488,524.20
1885	34,307	14.69	....	......	....	192,390.15	6.57	204,895.51	18,114,934	30.95	715,539.89	....	....	....	......	....	920,435.40
1886	29,399	15.83	....	......	....	141,759.33	5.73	141,759.33	12,222,086	24.69	565,882.58	....	....	....	......	....	707,641.91
1887	23,130	14.81	....	......	....	115,434.05	5.86	113,125.37	8,884,761	22.54	397,148.82	....	....	....	......	....	510,274.19
1888	15,367	12.75	....	......	....	94,232.22	7.03	88,578.29	7,187,383	26.81	316,963.59	....	....	....	......	....	405,541.88
1889	17,946	12.91	....	......	....	86,118.66	5.50	80,607.07	4,910,366	15.67	186,839.43	....	....	....	......	....	267,446.50
1890	9,397	12.97	....	......	....	40,427.47	4.95	42,287.13	2,285,544	14.00	99,078.33	....	....	....	......	....	141,365.46
1891	6,660	12.25	....	......	....	24,528.40	4.20	24,234.06	1,096,115	9.38	47,406.97	....	....	....	......	....	71,641.03
1892	6,615	11.20	12.498	......	$ 258.33	30,482.48	5.19	26,672.17	1,031,959	8.80	41,794.34	....	....	....	......	....	68,724.84
1893	6,776	12.70	1.710	......	35.35	38,393.63	6.50	30,023.82	1,812,897	15.30	65,445.58	....	....	....	......	....	95,504.75
1894	5,165	14.30	....	......	....	17,854.26	4.00	11,248.18	1,031,098	11.60	32,170.26	....	....	....	......	....	43,418.44
1895	299	14.80	....	......	....	1,341.99	5.30	876.32	110,212	21.70	3,559.85	....	....	....	......	....	4,436.17
1896	2,392	16.20	....	......	....	5,321.31	2.60	3,570.60	147,801	3.68	3.369.86	....	....	....	......	....	6,940.46
1897	2,500	14.80	43.144	......	891.79	5,311.50	2.50	3,176.28	238,595	5.60	8,541.70	....	....	....	......	....	12,609.77
1898	571	14.10	....	......	....	3,254.62	6.60	1,896.14	263,938	26.90	9,976.85	....	....	....	......	....	11,872.99
1899	133	11.10	....	......	....	535.09	4.60	318.80	67,094	28.40	2,999.10	....	....	....	......	....	3,317.90
[1]1900	587	12.60	8.078	......	166.97	4,401.09	8.60	2,702.71	255,908	24.90	11,183.18	....	....	....	......	....	14,052.86
[2]1900	393	14.44	22.809	.068	471.46	2,406.19	7.16	1,477.64	137,378	20.40	6,003.42	2,546	$ 412.20	....	......	....	8,364.72
1901	696	14.75	14.435	.024	298.37	5,018.33	8.52	2,958.30	132,662	11.30	5,744.26	40,242	6.482.99	....	......	....	15.483.92
1902	1,383	13.20	86.169	.071	1,781.11	10,450.12	8.70	5,450.78	161,057	6.70	6,553.41	46,918	5,454.69	....	......	....	19,239.99
1903	5,519	15.60	509.826	.109	10,538.00	25,326.97	5.44	13,676.56	93,833	1.00	3,975.70	6,213	822.29	....	......	....	29,012.55
1904	1,610	14.37	31.357	.023	648.15	6,673.84	4.84	3,857.48	246,464	8.90	10,735.97	....	....	....	......	....	15,241.60
1905	2,050	18.18	33.081	.020	683.78	14,533.48	8.64	8,865.42	827,443	24.59	38.666.41	....	....	....	......	....	48,215.61
1906	3,235	15.05	368.124	.133	7,609.12	26,940.08	9.80	18,211.49	359,402	6.54	20,485.91	....	....	....	......	....	81,242.10
1906	923	10.30												563,659	34.04	$ 34,935.58	
1907	500	12.80	23.360	.053	482.85	2,105.61	4.81	1,389.70	127.462	14.60	6,908.44	....	....				170,569.94
1907	4,885	9.80												2,713,669	30.78	161,788.95	
1908	1,057	13.60	13.996	.015	289.30	4,049.49	4.44	2,146.23	183,543	10.05	8.619.66	....	....				39,269.60
1908	1,013	13.90							21,687					597,004	34.20	28,214.41	
1909	3.979	16.40	290.367	.087	6,001.88	22,056.30	6.63	11,358.99	451,080	6.78	22,447.13	....	....				104,162.02
1909	1,997	11.48							74,614	2.10				1,149,179	32.57	64,354.02	
[3]1910	5,821	14.71	2,096.89	.422	43,342.72	146,081.21	29.42	78,883.85	369,439	3.72	16,255.32						183,909.84
[4]1910	3,469	13.46	65.51	.022	1,354.09	7,553.42	2.52	4,078.85	315,338	5.25	13,874.87	157	19.94	483,337	......	26,100.20	
1911	6,062	15.94	1,030.72	.202	21,304.98	59,244.57	11.62	31,399.62	794,604	7.78	35,757.18	16,286	2,035.75	233,152	......	13,289.66	103,787.19
	232,828		4.652.074		$96,158.25	1,275,595.84		$1,116,939.13	78.394,885		$2,266,232.91	112,362	$ 15,227.86	5.740,000		$328,682.82	$4,823,240.97

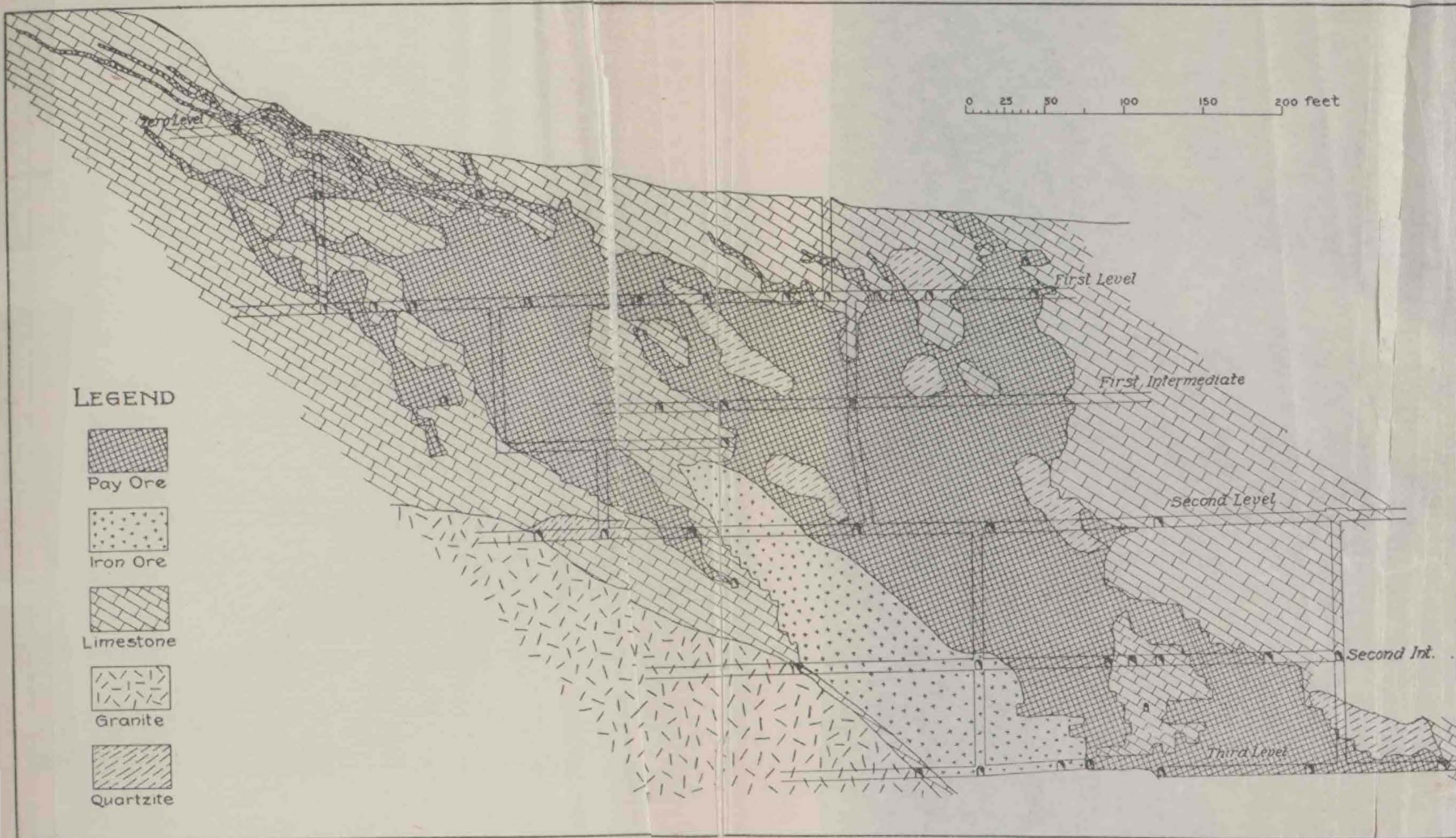
[1] To September. [2] October to December. [3] From No. 6 level to 200 feet above. From levels 4 and 5.

the fault. Plate XXII shows, by the position of detached masses of quartzite surrounded by ore, the broken character of the rock. The same plate shows also the size and geological position of the largest ore body. On the upper levels the ore was chiefly between limestone walls and many feet from the granite. The ore was in small part in, or in contact with, the "parting quartzite".

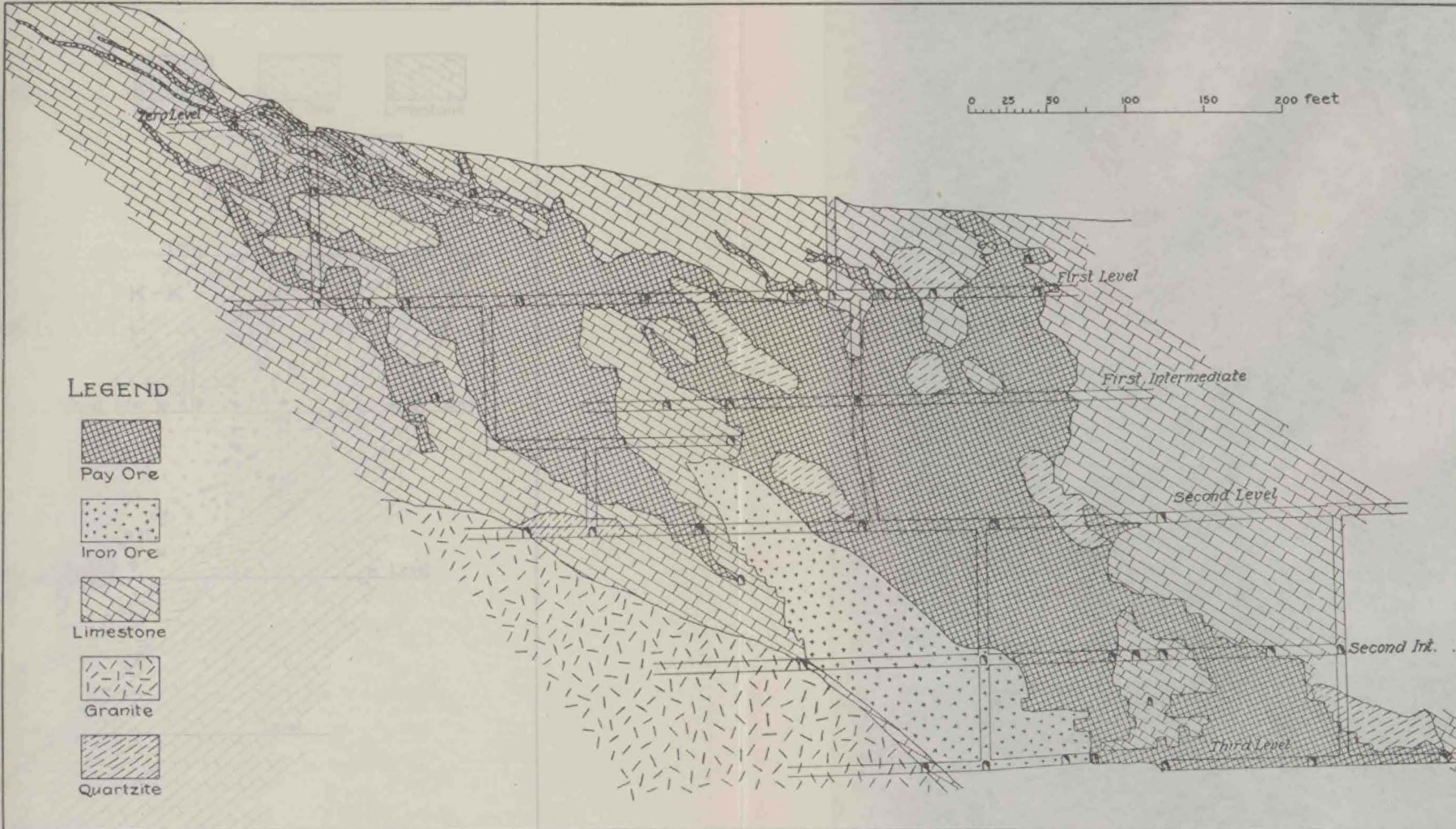
The main shoot held its course in the fault fissure, entirely in the limestone and quartzite, at a practically uniform distance from the granite, down to No. 4 level. Below No. 4 level it gradually approached the granite until, at No. 6 level, it is in contact with the granite hanging wall of the fault, and thus continues to the lowest depth reached in the mine. Below this shoot, in and near the same fault, a copper-ore shoot was mined from No. 4 level to 50 feet below No. 5, where the copper ore seems to grade into silver-iron ore. Between levels 4 and 5 the granite northeast of the fault formed the footwall of the copper-ore shoot which was about 300 feet, horizontally, southeast of the main shoot. The two shoots, gradually converging, united just above No. 6 level.

Although mineralization was continuous from Zero level to the bottom of the winze below No. 6, from No. 4 to about 200 feet below No. 5 payable ore bodies were connected by only narrow iron-stained joint-planes. In at least one place below No. 5, such a mineralized streak connected two large ore bodies only three or four feet distant from each other. In this part of the mine, however, the rock is badly broken and the ore seems to have been in large part a little northeast of the fault. The copper-ore shoot was continuous.

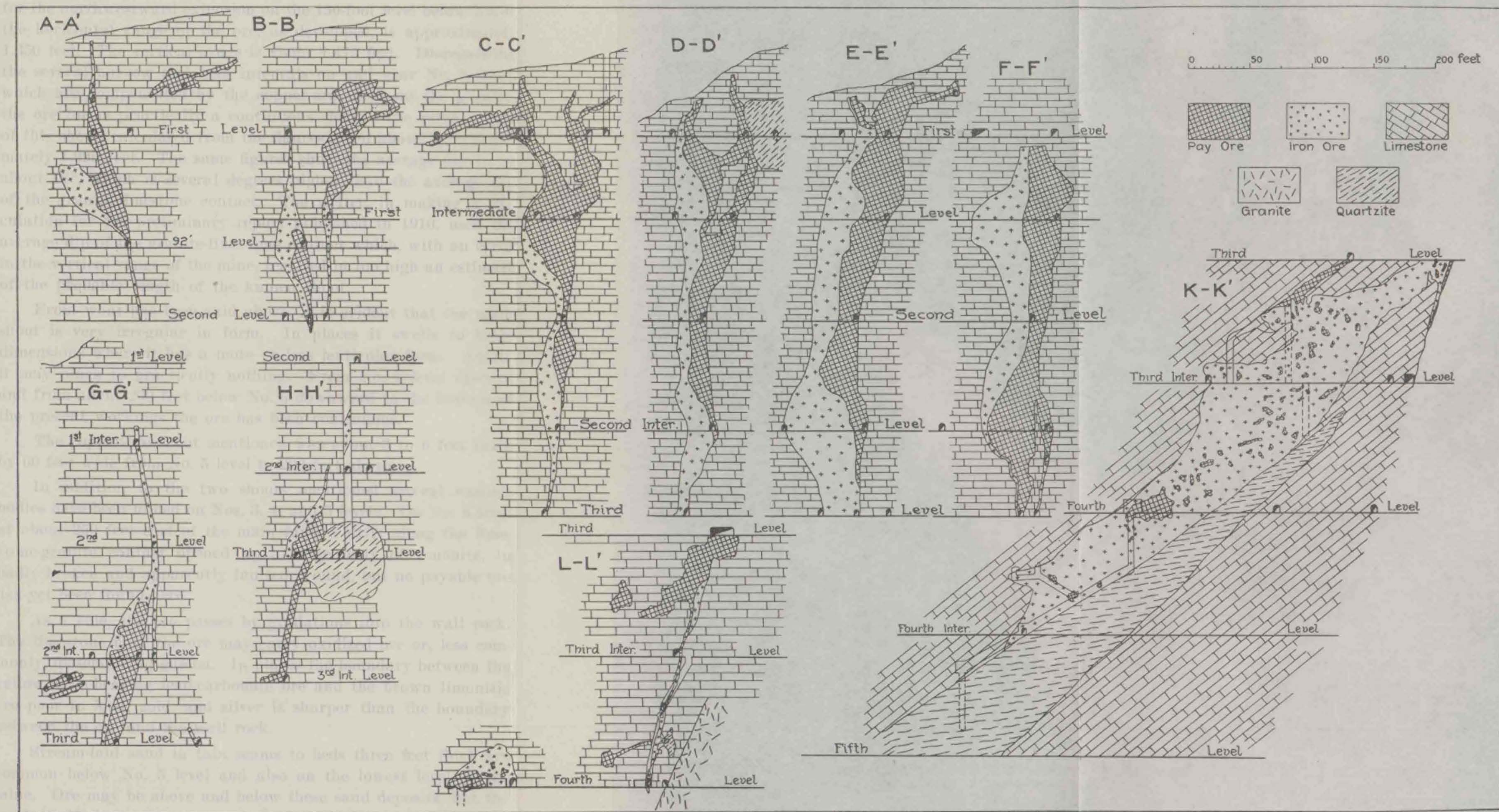
The main shoot had larger dimensions on No. 3 than on any other level. Here the maximum width was 80 feet, and stope length 200 feet. On No. 4 level the maximum width was 60 feet, and stope length 170 feet. On No. 5 level the ore body averaged about 25 feet wide by 50 to 60 feet in stope length. On No. 6 level the stope length was 96 feet. For half this distance the shoot was two sets wide (11 feet); for the other half the average width was 5 or 6 feet. When seen, the stope was 120 feet high, vertically, and still in ore. At 50 feet above the tunnel level the ore body was nearly three sets wide through a stope length of several sets. On the 150-foot level below No. 6, the stope length is 70 feet; the greatest width is 17 feet.



SECTION OF THE DONNA MINE ABOVE THE THIRD LEVEL



SECTION OF THE MADONNA MINE ABOVE THE THIRD LEVEL



CROSS-SECTIONS OF MADONNA ORE BODIES

Measured on the plan of the mine, and making allowance for the northwestward extension on the 150-foot level below No. 6, the horizontal range of the ore, as developed, is approximately 1,350 feet. The vertical range is about 1,475 feet. Disregarding the several narrow and lean intervals on and near No. 5 level, which are compensated by the copper-ore shoot on the granite, the ore forms practically a continuous shoot. The pitch length of this shoot, calculated from the figures given above, is approximately 1,990 feet. The same figures show the average dip to be about 48°, which is several degrees higher than the average dip of the granite-limestone contact. The writer, in making a calculation for the preliminary report published in 1910, used the average dip of the granite-limestone contact which, with an error in the vertical range of the mine, resulted in too high an estimate of the probable length of the known shoot.

From what has been said above, it is evident that the main shoot is very irregular in form. In places it swells to large dimensions where it has a more or less lenticular form. Again, it may pinch to practically nothing. From No. 4 level upward and from about 200 feet below No. 5 downward to the bottom of the present workings the ore has been continuous.

The copper-ore shoot mentioned was about 3 to 6 feet thick by 60 feet wide from No. 5 level to 200 feet above.

In addition to the two shoots mentioned several smaller bodies have been mined on Nos. 3, 4, and 5 levels. On No. 6 level at about 250 feet east of the main fault a drift along the limestone-granite contact opened up a large body of limonite, in badly broken and apparently faulted ground, but no payable ore has yet been found here.

As a rule, the ore passes by gradations into the wall rock. The limestone near the ore may carry oxidized ore or, less commonly, disseminated galena. In places the boundary between the yellow, iron-bearing lead-carbonate ore and the brown limonitic ore poor in lead, gold, and silver is sharper than the boundary between the ore and the wall rock.

Stream-laid sand in thin seams to beds three feet thick are common below No. 5 level and also on the lowest level of the mine. Ore may be above and below these sand deposits, but the sand itself does not carry values. A vein-like mass of small distorted quartz crystals borders the streak of high-grade ore below No. 6 level.

Character of the ore.—Excepting bunches of residual galena and a negligible quantity of possible telluride, all the ore hitherto produced by the Madonna has been oxidized ore. From the surface to No. 3 level the ore of the main shoot was chiefly silver-bearing, yellowish lead carbonate which carried 5 to 7 ounces silver per ton, 25 to 30 per cent lead, and an excess of iron. Between levels 3 and 5 the ore was chiefly brown limonite that carried about 5 to 7 ounces silver per ton, but only 2 to 10 per cent lead. A few hundredths of an ounce of gold per ton was found in part of the ore on No. 5 level. From No. 5 down to the 100-foot level below No. 6, the quantity of iron and lead has remained fairly uniform while the amount of gold and silver has steadily, though irregularly, increased. Where the ore was in contact with the granite it carried an excess of silica. On the 150-foot level below No. 6 the ore carries high values in gold and silver, some lead, and 10 to 25 per cent excess silica. The last three carloads from this level averaged 1.06 ounces gold and 121 ounces silver per ton and 7 per cent lead.

A narrow streak of high-grade ore one to 6 inches wide accompanies the ore on the lower levels. This streak is usually not more than one to five feet from the limestone and roughly follows the limestone wall—that is, where the ore body widens the streak bows northeastward. This streak is also described as very irregular in dip; in places it is nearly flat, in others it dips steeply. Samples from this streak show two varieties of ore. One variety is brown and composed chiefly of small cerussite crystals with interstitial limonite. The other variety is dark brown to black, earthy or sooty material which contains much cerargyrite, minute grains of argentite and pyrite, and minute crystals of cerussite and quartz. On assay, by Mr. Watts, the first variety yielded 10.40 ounces gold and 756.40 ounces silver per ton, and 48.0 per cent lead; the second variety carried 65.10 ounces gold and 5,974.90 ounces silver per ton and 24.30 per cent lead.

Over $300,000 worth of zinc ore, smithsonite and calamine, has been mined on levels 4 and 5 in recent years. But a small part of this ore came from No. 5 level and not any has been found below that level. Specimens on the dumps at the higher levels indicate that the zinc ore may run nearly to the surface. As shown in the table the zinc ore proper carries 30 to 34 per cent zinc in carload lots. The zinc ore body is very irregular in shape. It ranges from a few inches to 12 feet thick by 15 feet wide. The greater part of the zinc ore lies below and in contact with the main body of silver-bearing limonite, though it is also found bordering the copper ore.

The copper ore was chiefly malachite with limonite. It carried silver, lead, and 1.5 to 12 per cent copper. On and near No. 5 level it carried as high as .12 ounces gold per ton.

On No. 4 level, in addition to the copper-ore shoot and the main body of low-grade ore, a smaller lenslike body was mined which carried .04 to .25 ounces gold and 5 to 6 ounces silver per ton, and 2 to 10 per cent lead. No occurrence of gold was reported above No. 4 level.

HAWKEYE MINE

This mine was opened much more recently than most of the mines of the Monarch district and all parts of it, except one winze, are accessible. The main tunnel was driven about S. 45° E. 550 feet in granite to the granite-limestone contact, and thence along the contact 300 feet, bearing S. 20° to 25° W. the greater part of the distance. Along the contact the granite forms the hanging wall, the plane of contact dipping northwestward 40° to 60°. Near the breast of the tunnel an ore shoot was encountered which has been worked upward nearly 200 feet along the pitch and, when examined, had been worked 75 feet along the pitch below the tunnel level. Above the tunnel level the ore body removed would average perhaps six to eight feet each way in cross-section. Granite forms the hanging wall which dips northwestward 25° to 40°. In July, 1912, at the bottom of the winze, this shoot was 30 feet wide and in the middle was seven feet thick; it thinned to three feet at the south side and two feet at the north side. The ore at the bottom of the winze was chiefly silver-bearing lead carbonate and limonite with some galena, and was said to run about $14.00 per ton in carload lots.

Five hundred seventy feet from the tunnel entrance a cross-cut was driven through the limestone to the east limb of the synclinal fold where it cut an ore shoot lying on the granite footwall which dips northwestward 28° to 40°. A winze has been sunk a short distance, and the ore has been stoped out above the tunnel level for 250 feet along the pitch. The ore body was largest a short distance above the tunnel level with a maximum width of 66 feet. The stulls here are four to nine feet long with an average of perhaps six feet. About 85 feet higher the shoot was 55 to 60 feet wide, and nearly eight feet thick. At this point a fault of small displacement was seen in the foot-wall of the stope. The strike of the fault is nearly coincident with the direction of the pitch of the shoot—that is, the ore is found along the line of faulting. The upthrow is on the southwest side and the displacement is about three feet.

The ore showing at the head of the stope is scarcely three feet thick, a fact which evidently discouraged further development work at this point. It is very probable that the miners left the main shoot. Here the granite wall stands nearly vertical and strikes N. 20° E. which is the normal strike of the granite-limestone contact in this vicinity. The ore shoot pitches about N. 40° W. through most of its known extent. The miners followed the contact mentioned some distance S. 20° W. instead of their former course about S. 40° E. A bend of about 60° was, therefore, made. A drift along the contact toward the north would demonstrate whether or not the workmen turned away from the main shoot. The ore of this shoot is chiefly silver-bearing lead carbonate with some galena and is said to be of higher grade than that of the shoot near the breast of the tunnel.

The only map at hand is one based on compass readings and paced distances and can not, therefore, be more than approximately correct. From the relations of the two shoots mentioned, as platted on the sketch map it seems not improbable that the shoots may meet at the bottom of the syncline. If they do so meet and at whatever distance below the tunnel level, a good ore body is likely to be found at the bottom of the fold.

It is proposed to develop the Hawkeye property by driving a tunnel, No. 3, about 200 feet lower than the tunnel through which the mine has been worked. This lower tunnel, which has been driven 300 feet or more in the granite had not yet reached the limestone when the writer visited the district in 1912.

The Hawkeye mine was idle in 1909. In 1910 it was producing for several months, but was idle again in 1911. In July, 1912, a small force was taking ore from the winze near the breast of the tunnel.

The mine is equipped with electric hoist and fan and electric lights.

SILENT FRIEND AND FAIRVIEW MINES

There is little doubt that the Silent Friend, with the Fairview, ranks third among the mines of Monarch Hill in total output to date. As neither the Silent Friend nor the Fairview has been worked on a large scale for many years, most of the old stopes are inaccessible. However, the writer has seen part of the old workings on the second, third and fourth levels.

The main tunnel of the second level was started in the Ordovician limestone and driven about S. 75° E. to the limestone-granite contact about 700 feet from the portal. Ore was encountered at about 200 feet from the portal, and was stoped upward at least 50 feet. The ore removed was mainly oxidized, but when the mine was visited there remained several patches of galena. Blocks of galena a foot in diameter have been recently removed from the stope. A winze nearby, about 3 by 5 feet is reported to have been sunk in ore 100 feet. The ore shoot was in what appears to be a fault that was described in the chapter on structural geology. Crosscuts several hundred feet long were driven into the limestone both near the granite and at a distance of a few hundred feet, but no ore was found except that already mentioned.

The Silent Friend No. 3 tunnel, starting on the Fairview claim, was driven for a considerable distance near the contact between the limestone and granite on the west limb of the synclinal fold. Though the tunnel in this part of the course is mostly in limestone, masses of granite forced into the limestone by shearing stresses are frequently seen. Several carloads of oxidized ore have been taken from the border of an old stope on this level by the Sundbye Leasing Company during the past few years.

The Silent Friend No. 4 tunnel, starting in the granite, was driven southeastward into the limestone. At about 865 feet from the portal of the tunnel a winze said to be 140 feet deep, was sunk on the Fairview claim. At the time of examination there was about one foot of good carbonate ore showing at the side of the winze not far below the tunnel level. Presumably the ore at the center of the shoot was much thicker. The ore shoot, which here pitches toward the northwest, is said to have been worked out nearly to the surface on the Silent Friend claim, and was probably the same as that seen on the third level. Since the hanging wall is granite and the foot-wall is limestone it seems probable that this may be the same shoot as that near the breast of the Hawkeye tunnel. Whether or not the second and larger shoot of the Hawkeye mine was opened on the third and fourth levels of the Silent Friend is not known to the writer since only part of these levels are now accessible.

Just north of the winze on the fourth level is a sandy deposit about two feet thick and 14 to 16 feet wide. This deposit, which is composed chiefly of quartz sand with some calcite, is stratified, cross-bedded, and somewhat consolidated. The sand has an appearance similar to that of sand laid down by running water on the surface; it was evidently deposited by descending ground-water which here flowed in a channel of considerable dimensions.

The late Mr. D. F. Hamilton, who was once superintendent of the Silent Friend and Fairview mines, kindly furnished the information which follows. The main Silent Friend ore shoot, whose average dip was about 45° N. 34° W., was stoped continuously through a vertical range of nearly 700 feet. This gives a pitch length of nearly 1,000 feet. The shoot had a maximum thickness of 50 feet and was square-set throughout the entire distance through which it was worked. The shoot, following a somewhat spiral course, was in part close to the granite but ran out into the limestone 40 to 60 feet in places. It was thinnest where dipping toward the granite. The best ore was galena which carried 20 ounces silver per ton and about 70 per cent lead. Where the ore was near the granite it carried a small quantity of gold.

WILSON MINE

This mine has been developed through two tunnels on the Wilson and Kuter claims. In the summer of 1909, leasers were shipping from the lower tunnel a few carloads of zinc-lead ore which had been left on the hanging wall when the mine was formerly producing. The total thickness of the vein, where seen, was five to six feet. All but about two feet from the upper part had been removed several years ago.

ECLIPSE MINE

The Eclipse was one of the first mines of the district to produce ore in considerable quantity. There is no doubt that in output it ranks next to the Madonna.

A good idea of the geological conditions in the Eclipse mine may be gained from an examination of the plan and section (Figs. 12 and 13). The ore is found in two distinct shoots—one lying on the granite, the other just below the quartzite. The granite shoot extends below the fourth level while the quartzite shoot was lost several hundred feet above. At this point a thrust fault hading S. 58° W. brings the ore up against the end of the quartzite stratum which forms the footwall on the northeast. In this fault fissure the ore was galena with lead carbonate. Several pieces of solid galena four to five inches in diameter may still be seen. A few feet below in the same stratigraphic position is a large body of limonite reported to carry a small amount of silver and gold but of too low grade for shipping. No effort has been made to determine whether or not the ore body continues below the quartzite northeast of the fault. It is not clear whether the faulting at this point occurred before or after the ore deposition. Indications point to the former alternative but the evidence noted was insufficient to justify a conclusion. There is strong evidence that this is the Mayflower fault, and if so, it was probably formed prior to mineralization. A short distance southeast higher up in the stope, grooves on the hanging wall indicate that movement on this plane has been in part comparatively recent.

Mr. J. L. Farrell, former superintendent of the mine, gives the following information. The quartzite shoot, discovered at the surface, was cut successively by Nos. 1, 2, and 3 levels. On No. 2 level there were 110 square sets (4 by 5 ft.) on the sill floor in the quartzite shoot, and the size of the ore body remained practically the same up to No. 1. The shoot grew narrower below No. 2 where it formed a stull-stope 5 to 12 feet thick from No. 2 to No. 2 intermediate. Below this the ore was somewhat bunchy. The granite shoot was cut successively by levels Nos. 2, 3, and 4. The thickest part of this shoot was encountered on No. 3 level where it was about 25 feet thick by 80 feet wide. Both shoots bear slightly to the right of the dip as they descend.

The bulk of the ores shipped carried their chief values in lead and silver. Before 1893 the shipments carried 25 to 50 per

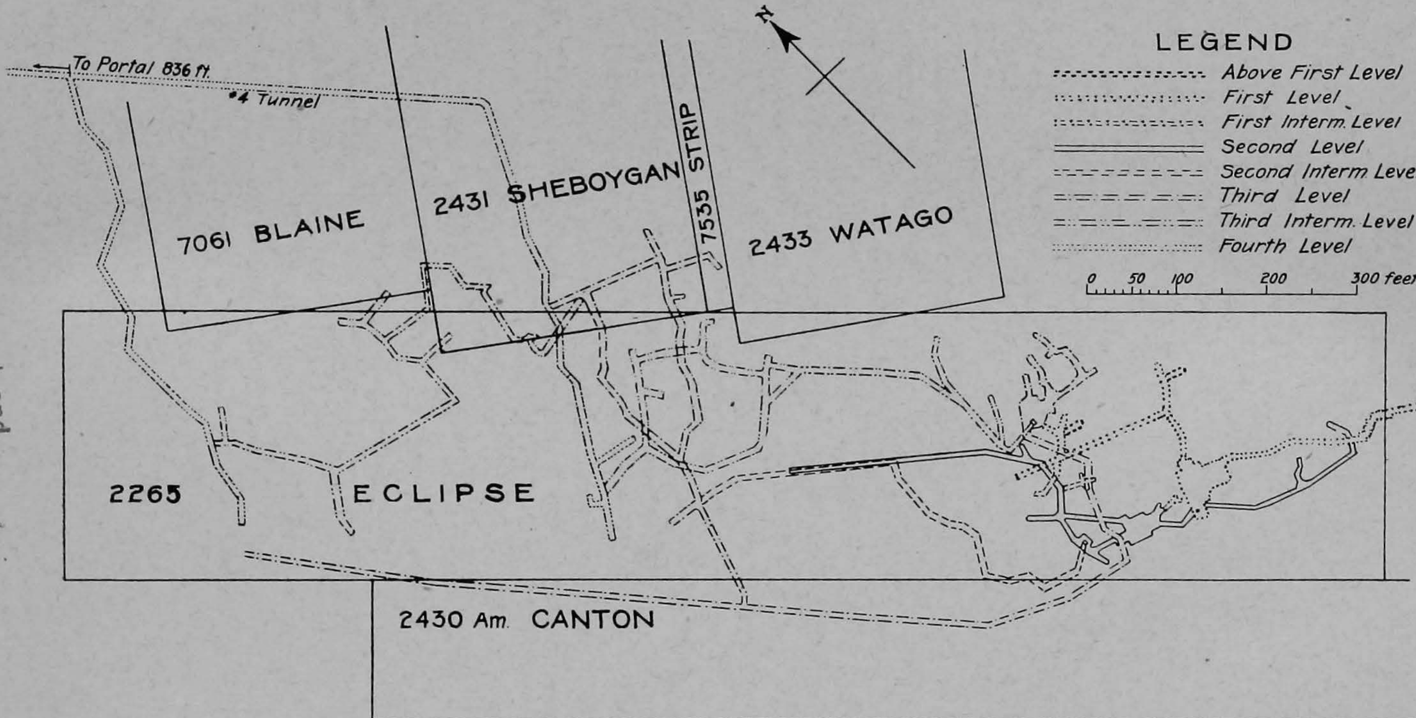


Figure 12.—Plan of the Eclipse mine.

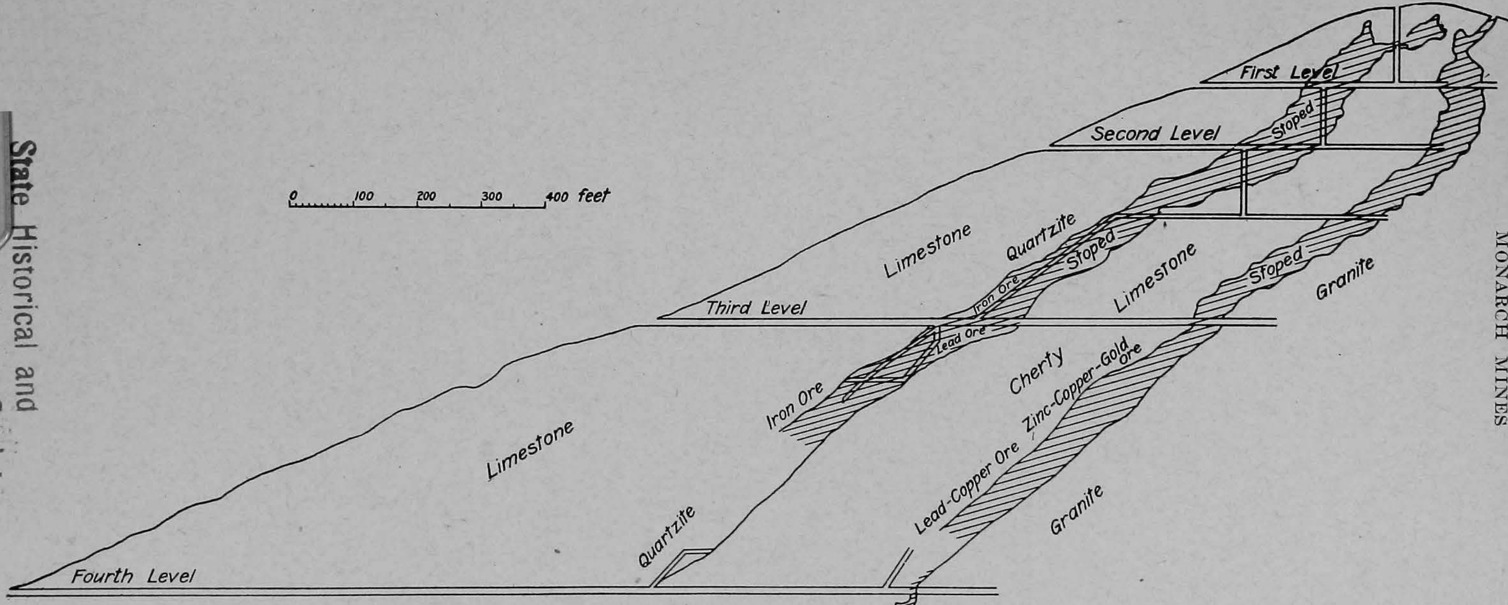


Figure 13.—Section of the Eclipse mine. Since this drawing was made a winze, just above the granite, has been sunk, from the fourth level, 300 feet (pitch length).

cent lead, but later, ore was shipped which carried only 5 per cent lead. About half the lead content was in the carbonate form, the remainder was sulphide. In general, the higher the lead content, the greater were the silver values. The highest silver returns in a carload lot were 28 ounces per ton. The silver averaged about 8 ounces per ton. The ore shipped since 1893 has carried a small amount of gold.

A considerable body of zinc carbonate and zinc silicate was found above the silver-lead ores in the granite shoot from No. 2 intermediate to No. 4 level. This ore carried silver values and was sometimes mixed with the lead ores in such proportion that the zinc content was kept below the 10 per cent limit fixed by the smelter. Excepting a few carloads shipped within the past few years the zinc ore was never sold as such by the company, but in 1905-6 the Paul brothers, who were working the mine under lease, shipped considerable zinc ore. A small amount of copper ore occurs in the granite shoot also, but no zinc or copper was found in the quartzite shoot.

In 1909 this mine was leased by the Giant-Eclipse Mining Company; a few of the old levels and stopes were cleaned out; and considerable ore has been shipped. There is a large amount of low grade zinc ore in sight. Preparations are now being made to ship low-grade zinc ore from above the fourth level.

When the writer visited the Eclipse mine in July, 1912, the winze below the fourth level, started in the shoot just above the granite, had reached a depth of 300 feet on the pitch. A streak of ore was followed all the way down. This streak began to widen at 250 feet below the fourth level and at 300 feet about eight by ten feet of ore was exposed. The ore here was chiefly limonite carrying low values in lead and copper. Where seen, the best copper ore—chiefly malachite with much limonite—was on the footwall at the northeast side of the ore body, and did not extend across to the southwest side. The ore is evidently in and near the fault plane which showed a displacement at this point of at least one foot. When the mine was visited the ore bins contained about two carloads of ore from this winze. Later in the year, Mr. Clyde H. Jay, of the leasing company, wrote that developments showed the ore body to be about 16 feet thick and to cross the course of the winze at an acute angle. Mr. Jay reports that about two feet of the ore on the footwall side runs .04 ounces gold and 15.8 ounces silver per ton, 32.8 per cent zinc, and very little lead; about four feet runs 22 per cent zinc; while the remainder is low-grade iron ore. The winze is being continued in the limestone, and it is proposed to crosscut for the ore 100 feet below.

No record of tonnage or gross values has been preserved by the Eclipse Company. But Mr. W. K. Spinney has kindly furnished the figures for the net receipts (gross value less freight and treatment charges) by years from 1887 to 1907 and Mr. Jay has given the figures of the output for December, 1909, to April, 1911. Disinterested miners in the district assert that the greater part of the total output of the Eclipse mine was produced before 1887. The report of the Director of the Mint, for 1883, states that at that time about 3,000 tons of ore was blocked out and that the bins contained about 1,000 tons, having an average value of $55.00 per ton. The net receipts from 1887 to April, 1911, were $585,670.

APRIL FOOL AND CONTACT MINES

Each of these mines was worked through a short inclined shaft in the limestone just above the granite. Both mines are now caved, having been idle since the eighties. The dumps are small; evidently but little development work was done. The April Fool is reported to have produced at least three carloads of ore and the Contact about 20 carloads. The ore is said to have been lead carbonate running high in lead. The report of the Director of the Mint, for 1889, gives the value of the output of the April Fool for that year as $1,072, the values being in silver and lead.

EVENING STAR MINE

The Evening Star ore shoot was discovered on the Little Chief claim from which it was worked through an inclined shaft sunk in the ore. The Evening Star tunnel, driven later along the contact, crossed the old workings about 70 feet above the end of the incline, but no ore has been taken from the tunnel. At the tunnel level the ore body was nearly two feet thick and 12 or 13 feet wide. A little galena, in rotten granite, can be seen on the foot-wall. Below this point the shoot is reported to narrow north and south and thicken at right angles to this direction.

It was possible to descend 120 feet, or more, from the collar of the incline in 1909. As a rule the ore lay close to the granite, but in the limestone. Some galena and limonite were seen in the limestone walls as a replacement. At 120 feet below the surface the width is 50 feet or more. The thickness is much greater than that at the tunnel level below. Mr. William Miller, one of the owners, states that low grade zinc ores extended from 40 to 130 feet below the surface but not to greater depth. He reports a total output of 600 tons which averaged $20.00 a ton. The principal values were in silver and lead; two carloads yielded 90 cents a ton in gold.

DELAWARE MINE

This mine was also worked through an inclined shaft which is now caved. Mr. Miller reports output and values approximately the same as those of the Evening Star. At the bottom of the shaft oxide of manganese was encountered, but carried no values.

BLACK TIGER MINE

This mine is reported to have produced eight or ten carloads of lead-silver ore in 1881. Judging from the workings, which were in part accessible in 1909, the main shoot was three or four feet thick at the tunnel level and 9 feet wide. The ore lay in limestone about three feet from the granite. The croppings show quartz and a little iron stain and galena.

FAIRPLAY MINE

This mine was located in 1878 by the Boone brothers and is reported to have shipped a considerable tonnage in the eighties. No figures are available for that period. Since the present owners have operated it the production has been 728 tons with a gross value of $14,974.00.

All the Fairplay workings are in the limestone above the "parting quartzite." The ore was formerly hoisted through two shafts but more recently a tunnel, a little above the level of the creek, was driven about 600 feet. Three or more upraises from the tunnel were driven in ore. A winze 90 feet deep has been sunk from the tunnel level. Slickensiding and several narrow calcite veins, seen on the tunnel walls, indicate faulting. Specimens of ore from the bottom of the winze contain a considerable proportion of galena.

LITTLE WONDER MINE

This mine has produced several carloads of ore from near the surface but the ores are pockety like those of other mines which have not yet been developed below the quartzite. In 1909 several tons of galena were taken from a pocket within 20 feet of the surface.

GREAT MONARCH MINE

The Great Monarch vein outcropped in a conspicuous fissure in a limestone cliff, and has been developed through a shaft and adit to a depth of perhaps 200 feet. Mr. Thomas Penrose states that the shoot was eight to ten feet wide for the first 30 feet, but narrowed to two inches for the next 60 feet. Below the adit level a winze was sunk 60 feet on the shoot which remained rather narrow but did not pinch out. The ore was galena and lead carbonate carrying about 200 ounces silver per ton. Within the past few years several carloads of zinc ore have been shipped from near the surface.

A tunnel has been driven some 1,200 feet just above the creek level on this property, but has not yet cut any payable ore bodies.

LITTLE CHARM MINE

This mine is on the same lead as the Great Monarch and has been worked partly through the discovery shaft and partly through the Great Monarch adit. The ores of this mine were similar to those of the Great Monarch but ran somewhat higher in silver. According to Mr. Penrose both silver chloride and stephanite were present.

For the Little Charm mine the record for high grade ore in a carload lot (10 tons) in the early days, was claimed. Mr. J. Scott Boyd, General Manager of the Monarch Pool Mining Company, gives the following as the smelter returns from this car: 0.48 ounces gold and 226.2 ounces silver per ton, 2.45 per cent lead, 7.65 per cent zinc and 0.15 per cent copper.

OTHER MINES

The Ben Bolt, Elkington, Paymaster, and Oshkosh have produced more or less ore, but all were idle when the Survey party was working in the district and the ore bodies were inaccessible. Several of these have had an output greater than a few that have been briefly described.

The Ingersoll mine south of Garfield is reported to have produced a carload of ore. Several tons of ore, galena with some iron oxide, lay in the shaft house in 1909. A body of specular hematite, said to be 40 feet thick, was opened in a shaft a few yards south.

The Thirty-Six-Thirty mine, southeast of the Ingersoll, is reported to have produced considerable ore many years ago. Much prospecting has been done in the vicinity, but no other payable ore has been found.

PROSPECTS

In addition to the two tunnels mentioned below, there are several prospects of more or less promise. In recent years, however, most of them have not been vigorously developed, only the annual assessment work being done.

Marshall tunnel.—This tunnel, which starts in the Ouray limestone, was being driven toward the limestone-granite contact in the summers of 1911 and 1912.

Monarch Contact.—The Monarch Contact tunnel was started in the limestone east of the "parting quartzite" and driven N. 37° W. 117 feet when the Lake fault was encountered. From this point the tunnel had been driven north along the fault about 600 feet when it was seen in July, 1912. At 400 feet from the portal a crosscut was driven to the "parting quartzite" which is here about 70 feet east of the fault. A drift was run about 120 feet just west of the quartzite.

The fault hades westward 10° where it was first encountered and about 35° in the breast of the tunnel. Although the limestone is badly crushed close to the fault, the walls, for the most part, stand fairly well without timbering. The limestone is more or less crystallized. Gouge, from a few inches to two feet thick, is continuous along the fault. In places, the granite and limestone have been crushed together and form a mass of uncemented fault-rock. In driving the tunnel it was feasible to pick down much of the ground without previously breaking it by blasting. The gouge is tight and dry and suggestive of rubber; it carries no mineral excepting occasional grains of pyrite.

Little patches of good ore were found at intervals in the fractured fault-rock. The determinable minerals are galena, sphalerite, and pyrite, and are chiefly in thin seams filling fractures in the marble or granite. Assays, made for the Survey by H. F. Watts, on three samples gave the following results:

	1	2	3
Gold, ounces per ton	0.18	0.10	0.08
Silver, ounces per ton	173.50	9.60	173.50
Lead, per cent	14.10	0.40	0.20

No zinc assays were made. No ore, in payable quantity, had been found in this tunnel when last seen by the writer.

Work along the "parting quartzite" shows that the distance between the quartzite and fault is widening toward the north, but the structural relationships in this vicinity make it reasonably certain that this divergence is local. If the faulting has been correctly interpreted the quartzite is cut by the fault somewhere south of the saddle west of Syncline Hill. The quartzite is more or less broken and shows considerable iron stain. A shaft a short distance southwest of the portal of the tunnel is nearly 60 feet deep. This was sunk 56 feet through morainal material, but the bottom of the shaft is in broken crystalline limestone.

MINES OF TAYLOR GULCH

In the early eighties there was much activity in Taylor Gulch and several mines are credited with a considerable output. Since the Survey began work in the Monarch district mining operations of greater or less extent have been carried on in the Lilly, Rainbow-Eagle Bird, New York, Last Chance, Shamrock and Major, Garfield, and Mocking Bird mines, most of which have produced ore. Beside the assessment work done by individuals on unpatented claims, the Jewell tunnel has been driven nearly 1,000 feet.

GARFIELD AND ALASKA MINES

These mines are now owned by the Eureka Mining & Reduction Company which owns a large group of recently patented claims on the east side of Taylor Gulch.

Garfield mine.—The Garfield mine has been worked through a tunnel which starts just east of the gulch, in the Ouray limestone, and crosscuts the sedimentary rocks to the limestone-granite contact about 1,000 feet east of the portal of the tunnel. Excepting about 300 feet just north of the breast of the tunnel, drifts have been run north and south of the tunnel nearly 2,000 feet along the contact or a few feet west of the contact. In

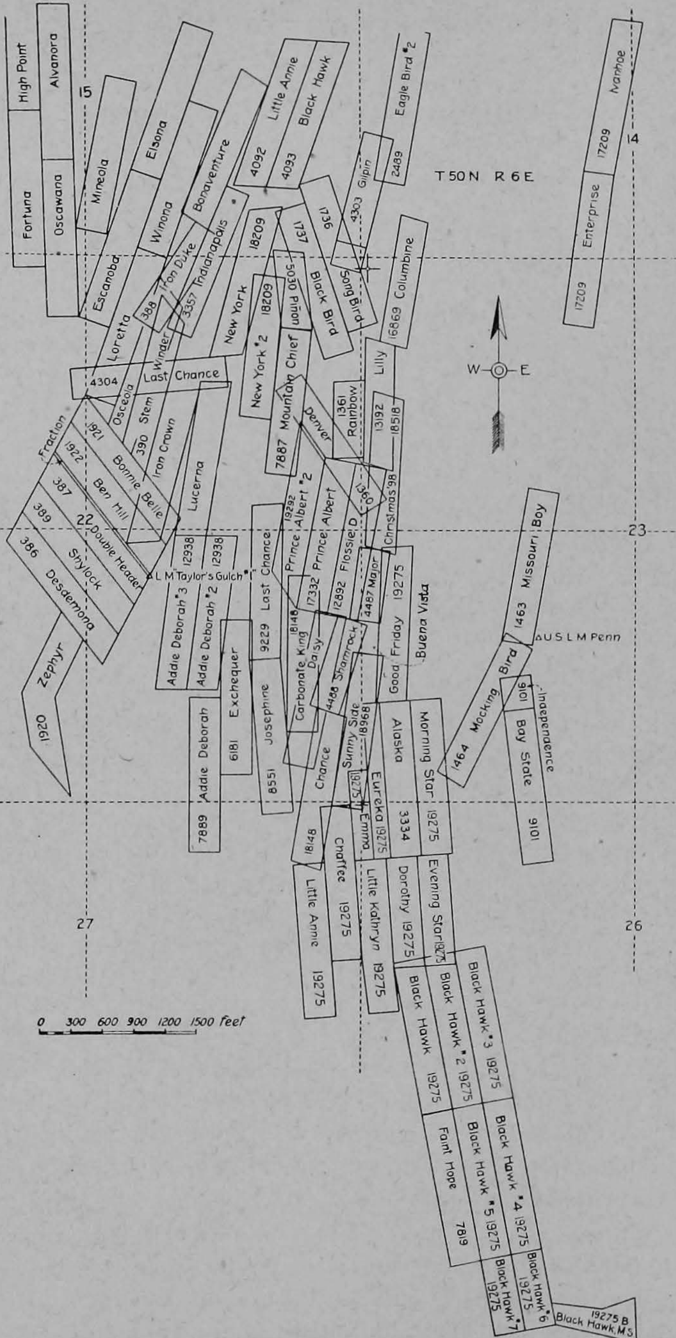


Figure 14.—Mining claims of Taylor Gulch. Patented claims are from maps by F. P. Black and H. J. van Wetering. Data for unpatented claims furnished by M. R. Jewell.

addition, the workings include several hundred feet of crosscuts and drifts as well as a few upraises and stopes. Some years ago, oxidized ore was stoped above the tunnel level a short distance south of the tunnel. This ore was in limestone not far from the granite.

In recent years the mine has produced but little. However, an ore body has been disclosed by the annual assessment work which was done to hold the claims prior to the issuance of the patent. In a drift on the tunnel level, north of the main tunnel, a vein of sulphide ore, varying from a few inches to 10 feet wide, has been followed about 600 feet. This vein is in the limestone, near the granite-limestone contact which it parallels. For the first 500 feet from the crosscut where it was first opened, the vein was narrow. At 500 feet north of the crosscut the vein widened to four feet where the drift passes to the east side of the vein. When seen by the writer, in July, 1912, the ore formed the west wall of the drift for about 100 feet. In this 100 feet the width had been determined at only one point by a crosscut; in this crosscut the vein was 10 feet wide. Near the north end of the known sulphide ore body, granite formed the east wall of the drift—that is, the vein was distant from the granite only the width of the drift. While the walls of the vein appear to be fairly sharply defined the wall rock contains a considerable proportion of disseminated ore, the amount decreasing with increasing distance from the vein. A few blocks of unreplaced limestone are found in the vein. An upraise, started on the sulphide vein passed into oxidized ore a few feet above the tunnel level. A drift from the upraise about 15 feet above the tunnel disclosed six inches of pyrite on the border of the oxidized ore in which the drift was run.

At 100 feet above the tunnel level the ore body seen by the writer at the top of the upraise, was 8 by 12 feet, and only one wall was showing. The ore was seven or eight feet thick in most of the upraise. At 35 feet a drift was run 60 feet south. For 50 feet of this distance the drift was in ore 18 to 30 inches wide. Oxidized ore was also found on the tunnel level about 100 feet north of the north limit of the known sulphides. The drift, continued for 75 feet on the oxidized part of the vein, showed the average width of the vein here to be about six inches.

The sulphides are chiefly sphalerite, galena, and pyrite, with a little pyrrhotite. Any one of these minerals, except pyrrhotite, may dominate locally. It is probable that the unassorted ore awaiting shipment in July, 1912, contained a carload, or more, that would carry at least 70 per cent zinc blende, or about 45 per cent metallic zinc. But little ore with so high content of galena was seen.

At 35 feet above the tunnel level the oxidized ore is largely limonite and cerussite. Some of the cerussite is well crystallized. Occasional small patches of galena which has escaped oxidation, may be seen surrounded by oxides and carbonates. This ore is reported to carry also silver values and a little gold and to average about $40.00 per ton. At 100 feet above the tunnel level the ore is of low grade, having a large proportion of iron oxides. The oxidized ore north of the sulphides on the tunnel level, was reported to carry high gold values with some silver and lead.

Alaska mine.—The Alaska was worked principally from 1886 to 1888. In 1898 Harrington and Anderson shipped a little more than a carload from this mine. Mr. Anderson gives the following information:

Forty-five feet west of the granite a shaft was sunk 110 feet on an east-west streak of ore. In all, there are about 1,000 feet of drifts at 30, 60, and 100 feet below the surface. The ore was galena, hard carbonate, and iron oxide. The carbonate ore occurred in a shoot about 10 to 18 inches wide, extending along the north-south drift 30 feet. The shoot pitched north about three feet for each foot of vertical descent. A few tons shipped by Harrington and Anderson ran $37.00 in gold and 14 ounces silver per ton, 18 per cent lead, and 32 per cent iron. The west wall was limestone; the east wall was gouge material which extended to the granite. The galena, which carried 20 to 25 ounces silver per ton, 60 per cent lead, and no gold, was found in pockets of iron oxide above and below the carbonate shoot. The iron ore carried $7.00 to $11.00 in gold and about 10 ounces silver per ton. It is not improbable that the Alaska ore was found not far from the upraise in the Garfield mine.

Garfield lower tunnel.—From the creek east of Garfield village a tunnel, through which it was proposed to work the property of the Eureka Mining & Reduction Company, has been driven over 2,200 feet along the limestone-granite contact, but the breast of the tunnel is still a considerable distance from the known ore bodies. No workable ore was found in the tunnel along the contact. However, a small amount of galena and zinc blende was discovered out in the limestone by crosscutting.

Equipment.—Near the creek, at the lower tunnel, is a power plant containing boiler, engine, and generator, while the tunnel is equipped with electric lights and electric drills. The mine, in the gulch above, is equipped with motor, fan, and an electric drill. Ore can be carried to the railroad by the Lilly tram which passes over the Garfield dump.

SHAMROCK AND MAJOR MINES

The Shamrock mine has been worked through a tunnel about 900 feet long from which extend several drifts, a few upraises, and winzes. Considerable ore was hoisted through a shaft before the tunnel was driven.

The limestone is much broken and apparently faulted. A porphyry dike having an easterly trend passes through the mine, and shows very abrupt changes in dip and strike. Mr. F. C. Watson, who is leasing this mine, states that he took a carload of ore, carrying 1.58 ounces gold and a few ounces of silver per ton, from a pocket just above the porphyry. The greater part of the ore which has been found in the mine was in pockets. The tunnel follows a lead several hundred feet, but the vein exposed in the roof is less than three feet wide.

The best ore found lay near the porphyry and quartzite, and in the quartzite. Prospecting near the granite has not been profitable here. No ore was found in the caves mentioned in Chapter VI.

The Major mine has been operated through two shafts and a short tunnel; one of the shafts is about 40 feet deep. The ore replaces limestone not far from a porphyry dike which is probably the same as the dike in the Shamrock mine. Recently one carload of ore, assaying about 12 per cent copper, was shipped from a body about six feet across. The ore is chiefly azurite, malachite, and melaconite. Most of the ore produced by this mine in former years was silver-bearing lead carbonate. Three or four carloads of copper ore have been shipped.

Most of the ore from the Major and Shamrock mines carries values in gold, silver, lead, copper, and iron. The two mines have produced about 1,000 tons of ore averaging $15.00 a ton net—that is, after paying freight and treatment charges.

LILLY MINE

This mine, which is owned by the Taylor Mountain Mining Company, is now worked through a tunnel 2,530 feet long. A few hundred feet from the breast a winze has been sunk 200 feet or more. The tunnel begins just west of the "parting quartzite," crosscuts the sedimentary beds to the granite contact, and continues north in the limestone but a few feet from the granite. For nearly the entire distance along the contact the tunnel follows a streak of limonite connecting several bunches and shoots of ore which have a maximum width of 8 or 10 feet on the tunnel level. The thickness is much greater. The best ore bodies on this level are of copper, but workable silver-lead and silver-iron ores have been encountered. (See fig. 15.) The largest stope on the tunnel level is 35 feet high by 100 feet long. Several stringers lead out into the limestone but until recent years none of them had been followed. In 1911 a crosscut was started on the tunnel level, about 100 feet north of the shaft and driven west into the limestone 175 feet. This crosscut encountered ore at 53 feet from the granite, according to Superintendent George H. Purmort, and was in ore 16 feet. An upraise was driven 30 feet in ore. The ore of this body is said to be silver-bearing cerussite which averages about 15 ounces silver per ton and 35 per cent lead. Farther north a connection was made through an upraise with the 230-foot level, that is, the level 138 feet above the tunnel. The upraise was driven in ore all the way except the first 27 feet. The ore body here is about eight feet wide and about 25 feet from the granite. In this body a bunch of about 7,000 pounds of almost pure cuprite, assaying 85 per cent copper, was found.

A few bunches of ore have been stoped out on the first and second levels below the tunnel. The ore is reported to have carried 3 to 40 ounces silver and $1.00 to $3.50 gold per ton and 10 to 15 per cent copper.

Most of the ore taken from the mine, from the surface to the 230-foot level, was hoisted through the discovery shaft. More recently much ore was mined on the 230-foot level and hauled out through the main tunnel below. Large bodies of ore are reported in the old upper workings but can not be profitably mined because of bad ground and rotten timbers.

As a rule quartzite lies against the granite wall wherever ore occurs and varies in thickness from a few inches to perhaps

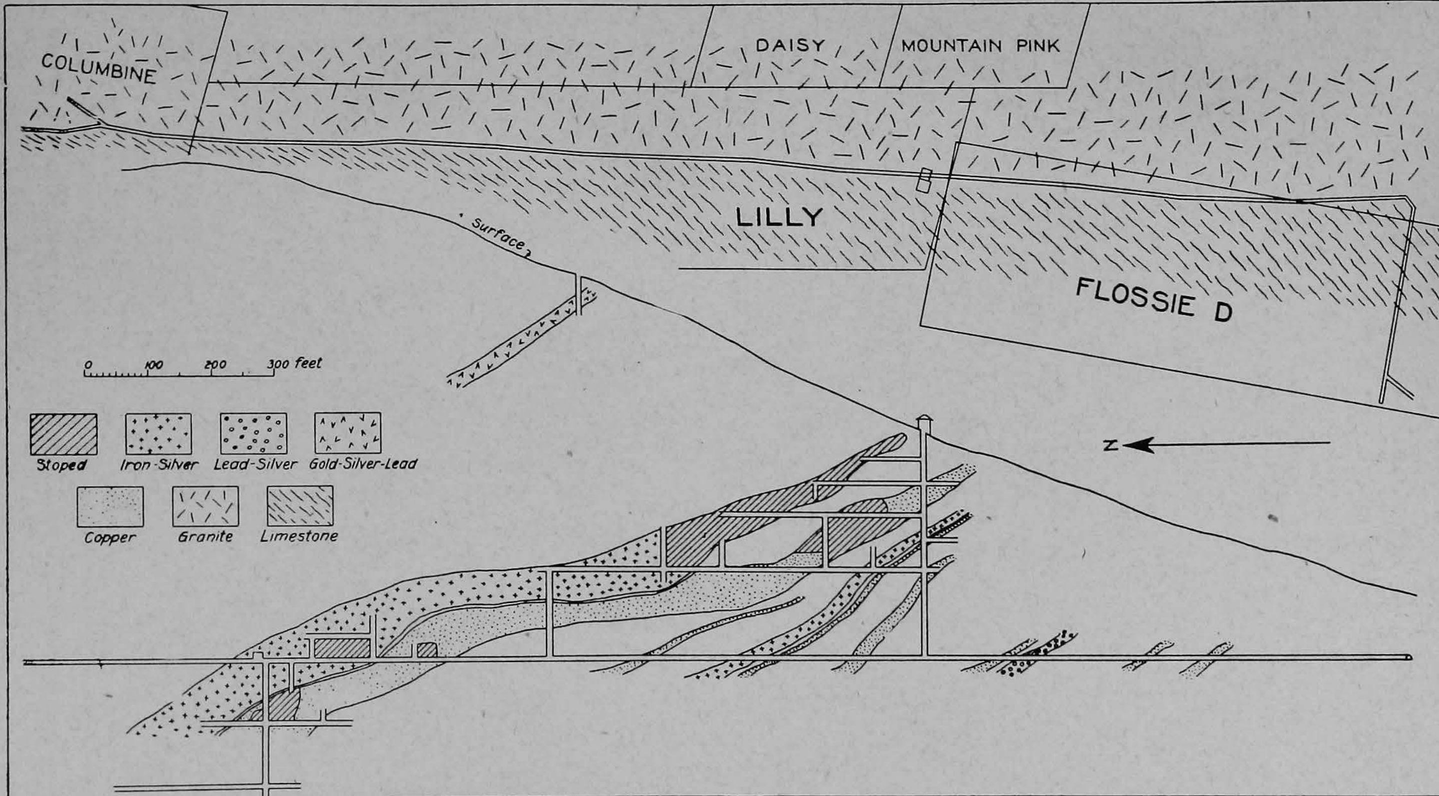


Figure 15.—Plan and section of the Lilly mine. The most recent developments are not shown.

six feet. It may be continuous but there are no crosscuts to it from the tunnel where ore is not found. A narrow porphyry dike follows the contact more or less continuously, sometimes in the limestone, sometimes in the granite. The limestone is considerably broken, movement having taken place in practically every direction as shown by the slickensiding.

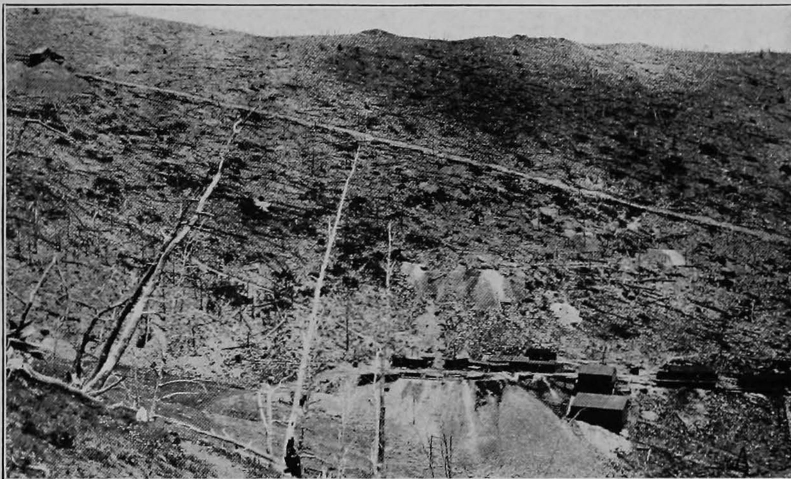
The ores of the Lilly mine are chiefly carbonates and oxides with some chrysocolla and considerable sulphide. The sulphides, which are chalcopyrite and copper-bearing pyrite have been found below the tunnel level and in smaller quantity nearer the surface. They are found associated with oxidized ores. Much of the chrysocolla is very pure but is usually in thin seams. In at least one place it occurs as a coating an inch thick or more on the walls of a small cave or fissure in the limestone. The copper ores are partly in limonite gangue, partly disseminated through limonite which also carries silver. About half the ore carries a small amount of gold.

Through the courtesy of President W. F. Norway we are able to give the following figures from the smelter settlement sheets showing the output of the mine from March 17, 1906, to January 18, 1910:

Output, 4,991.65 tons
Copper, 757,163 lbs. (wet assay).
Silver, 17,743.13 oz.
Lead, 4,637 lbs.
Gold, 67.44 oz.
Gross value, $103,111.20
Average value per ton, $20.66
Output from 1888 to Jan. 18, 1910:
Total tons produced, 8,827.15
Gross value, $173,898.71
Average value per ton, $19.70

About two-thirds of the ore has carried an average of 10 per cent copper. The remaining one-third was silver ore which carried very little copper. Until the end of 1907 the ore carried 30 to 40 per cent excess iron. In 1909 the mine produced 1,832 tons with a gross value of $26,121.34. This is the largest output for any one year in the history of the mine.

Between January, 1910 and April 30, 1912, the mine produced about 1,050 tons of copper ore averaging 9 per cent copper, (wet assay,) and 900 tons of iron-silver-lead ore. Since the be-



A.—LILLY MINE
Discovery shaft at upper left-hand corner

B.—MINES AND PROSPECTS AT HEAD OF TAYLOR GULCH
1. Rainbow-Eagle Bird; 2. Denver; 3. Jewell tunnel.

ginning of the year 1910 the mine has been operated only intermittently and by a small force. In the year 1912, only two men were working in the mine and but three or four carloads have been shipped each month. The company is planning to put a larger force at work early in 1913.

The mine is equipped with motor, compressor to operate the machine drills, an electric fan for ventilation, electric lights, and at the winze an electric hoist. The ore is carried by gravity over an aerial tramway 7,174 feet long to the railroad at Garfield.

RAINBOW-EAGLE BIRD MINE

Although very little work has been done on this property it is reported to have produced about $16,000 worth of ore. It is worked through two short tunnels near the surface. The ore occurs in a brown, ferriferous, crystalline dolomite overlying the "parting quartzite" and within 8 to 30 feet of an overlying porphyry dike or sheet which dips westward. The best ore body seen by the writer was 18 inches to 2 feet thick in a replacement vein parallel to the bedding of the sedimentary rocks. Mineralization has extended a foot or more into the inclosing rock on each side of the good ore. Two samples of the dolomite taken from the dump and assayed in the laboratory of the State Survey carried respectively 4.25 ounces silver per ton and a trace of silver.

Although lead is present in considerable quantity the chief values of the ore are in gold and silver. The lead occurs largely as galena. Some of the best silver values are carried by a streak of manganese oxides which extends throughout the length of the tunnel, 8 to 30 feet below the porphyry dike. The principal manganese mineral is psilomelane. Some quartz is present as a gangue mineral. Two small shipments from this mine in 1909 gave, according to the smelter settlement sheets, the values listed in columns 1 and 2 of the table below. Column 3 is an assay of a sample by S. B. Weld of Salida; column 4 is an assay by H. E. Burton of Leadville. Columns 3 and 4 are instructive in that they show the spotted character of the ore. Presumably the samples assayed were selected.

Tenor of Rainbow-Eagle Bird ore

	1	2	3	4
Gold, ounces per ton....	2.15	2.00	0.26	13.12
Silver, ounces per ton..	141.5	169.60	3,180.0	309.0
Lead, per cent.........	5.8	9.00	....	....
Zinc, per cent..........	11.2	....	....	....

In 1910 about $600 worth of ore was shipped from this property, but the values are not at hand. In 1911 there were several sacks of good galena at the mine.

Two shafts on the Eagle Bird claim north of the breast of the tunnels have opened a body of silver-manganese ore which has not proved sufficiently valuable to mine under present conditions. A sample taken from the dumps yielded on assay 7.50 ounces silver per ton, 24.70 per cent manganese, and 5.71 per cent iron; some silica and much lime carbonate were present. Two other samples which were not run for manganese assayed respectively 1.75 ounces and 2.60 ounces silver per ton.

The mine has been operated by primitive methods which could be profitable only for ore of very high grade. The ore was wheeled out of the mine on wheelbarrows, sacked, and packed over to Cree Camp on burros, thence hauled to the railroad at Maysville by wagon, and thence shipped by rail to the smelter. This mine was acquired, in 1911, by the Taylor Mountain Mining Company which has not yet operated the property.

MOUNTAIN CHIEF AND PINYON MINES

The Mountain Chief was one of the earliest producers, and is reported to have yielded some of the highest-grade ore of the district. It is stated that the first lot was packed on burros to Garfield, thence hauled 73 miles by wagon to Canon City, and shipped by rail from Canon City to the smelter at Omaha. Notwithstanding this heavy expense it netted a large profit. Mr. E. Gimlet states that Mr. J. L. Emerson later shipped 20 tons from this property, which returned a gross value of $10,600.

When visited in 1909 the shaft was half filled with ice, but the tunnel below could be entered. At about 60 feet from the entrance, the tunnel was filled with wáste from a crosscut in a porphyry dike which overlay the ore. Mr. Gimlet, a former superintendent at this mine, states that the ore was in a pocket and mostly within 70 feet of the surface. Its thickness at the upper part was about two inches and at greater depth was three feet. The Mountain Chief, Pinyon, and Song Bird are reported to have produced together a total of about $200,000.

The Pinyon, which joins the Mountain Chief, is said to have produced $22,000 worth of ore from one pocket which pinched out. No further work has been done. This pocket was but a few feet thick, having its greatest diameter parallel to the strike of the inclosing brown limestone. This limestone is a coarsely crystalline ferriferous rock similar in appearance to the dolomite of the Rainbow-Eagle Bird but carries little or no magnesia.

NEW YORK MINE

The workings of this mine are on the New York and New York No. 2 claims, on the west side of Taylor Gulch. On the New York claim, a tunnel 35 to 40 feet long, driven westward, cut through a body of limonite about 16 feet across in the direction of the tunnel. The ore is of too low grade to be profitably worked under present conditions. A second tunnel, started nearly 250 feet lower, on the New York No. 2 claim, has been driven westward 400 feet or more.

The lower tunnel crossed a highly mineralized zone, several yards wide, about 200 to 220 feet from the portal. A few tons of low-grade zinc ore containing calamine and smithsonite, were taken out. At about 230 feet from the portal a small quantity of zinc ore was found in the bottom of the tunnel. The ore was partly oxidized but contained a core of good sphalerite associated with diopside and garnet. The sphalerite carried a small amount of silver and gold. At 360 feet from the portal a westward-dipping ore body was encountered, which was 18 to 26 inches thick on the tunnel level and about 30 feet wide. In July, 1912, the ore had been stoped upward about 20 feet. Much of the ore is oxidized and includes cerussite, limonite, tenorite, azurite, and malachite. While a small part of the cerussite is very pure and well crystallized, the lead carbonate is present chiefly in the hard, compact form, and has an admixture of limonite and undetermined nonmetallic minerals. Some earthy-looking soft lead carbonate is present. The tenorite contains a large per cent of iron and is seamed by thin veinlets of azurite and malachite. Though much of the ore is oxidized a large proportion of galena is present.

The galena is very coarse, shows alteration to cerussite, and is not uncommonly seamed with malachite. The rock near the ore is more or less decomposed, but it contains much epidote with crystallized calcite as well as a pale greenish-white micaceous mineral, possibly a chlorite.

The smelter settlement sheet for the first shipment of two carloads (108,112 lbs. net) of ore from this level gives 14.0 ounces silver per ton and 33.2 per cent lead, 4.2 per cent copper, 4.5 per cent zinc, 13.7 per cent iron, and 13.0 per cent silica. The settlement sheet for the thirteenth carload shows .03 ounces gold and 32.5 ounces silver per ton, 25.35 per cent lead, and 4.4 per cent copper. The net value was $43.47 per ton. Manager M. R. Jewell writes that since this ore body was found, late in 1911, 14 carloads have been shipped; the first eleven had an average value of $33.82 per ton. Mr. Jewell also states that since the writer visited the mine in July, 1912, a body of zinc ore 7.5 feet wide has been uncovered in a drift south of the tunnel. The ore contains calamine and smithsonite; a smelter assay of a dozen samples across the ore body gave 33.8 per cent zinc. Not any of this ore has been shipped. Ore for several carloads is said to be in sight in the stope and drift. Shipments have been delayed by the slow process of packing the ore on burros to the Lilly tram. It is proposed to build a tram from the mine to the Lilly tram in 1913.

LAST CHANCE MINE

But little work has been done on this claim. When examined, a tunnel had been driven about 100 feet and several tons of ore had been taken out. The large body of limonite (gossan) at the surface, the fracturing of the sedimentary rocks and evidence of faulting, all indicate the possible presence of a workable ore body. A tunnel to develop this property has been started lower down on one of the Jewell claims, but when the district was visited in July, 1912, no ore had been encountered in this tunnel.

BONNIE BELLE, BEN HILL, FRACTION, DESDEMONA MINES

These mines, which are on one lead, produced some ore in the eighties and but little since. Only the Fraction, the least important of the group, could be examined in 1909. This was worked through a short tunnel and a winze about 50 feet deep. A vein three feet thick was found in a short drift toward the north. This vein is parallel to the bedding of the inclosing sedimentary rocks which dip 56° N. 75° W. A bedding fault is indicated by the slickensided hanging wall. This movement probably occurred after the ore was deposited. The writer is indebted to Mr. Everett Anderson for the following notes on the other mines of this group.

The Ben Hill shaft is 275 feet deep. Drifts were run north and south at 125, 175, and 225 feet from the surface. At the 175-foot level a drift running north 125 feet is the longest in the mine. At 30 feet from the shaft on this level a body of galena three feet thick was cut; this carried an average of 85 ounces silver per ton and 73 per cent lead. The ore was in the form of a shoot pitching northward and extending upward practically to the 125-foot level. Carbonate ore occurred on the border and in some places graded into the galena. The average tenor of the carbonate was 22 to 28 ounces silver per ton and 30 per cent lead. Between the 175- and 225-foot levels the ore was spotted. The bottom of the shaft is in an ore body seven feet thick, which assays 90 ounces silver per ton and 60 per cent lead. Water stopped the work here and a tunnel was driven to cut this lead about 400 feet below the bottom of the shaft, but no ore in payable quantity has been found in the tunnel, although it is supposed to have reached a point under the shaft.

The Bonnie Belle shaft is down 146 feet. At 60 feet a body of galena similar to that in the Ben Hill was discovered. This body is about six feet thick. With the galena was associated oxide of iron which inclosed masses of the ore. In places some carbonate of lead was found with the galena. This ore was in the form of a northward pitching shoot having a stope length of 60 feet. The vertical distance covered by the ore in the shaft was 40 to 50 feet.

The Desdemona shaft is 118 feet deep. Drifts extend north and south at 60 and 100 feet from the surface. The ore was largely galena in streaks and bunches with occasional large pockets of carbonate ore.

The total output of these claims is not known, but the Ben Hill shaft has produced $12,000 worth of ore.

Ore seen on the dumps and platforms at these mines was galena with both hard and soft lead carbonate. At the Bonnie Belle there is considerable breccia having sedimentary fragments in a granite matrix, indicating the proximity of the ore to the granite. Granite dikes occur a short distance west.

OTHER MINES OF TAYLOR GULCH

Several claims in Taylor Gulch produced small amounts of ore in the early days. The Denver-Rainbow, Indianapolis, and Stem Winder have each produced a carload or more. The ore in these claims was found near the surface in pockets or narrow veins, and but little work has been done to determine the extent of mineralization.

MISSOURI BOY, MOCKING BIRD, BAY STATE, AND INDEPENDENCE

These claims are not in Taylor Gulch proper, but just east of the east rim of the gulch. It is reported that about $3,000 worth of ore was shipped from the shallow workings of the Missouri Boy mine. The values were in gold, silver, and lead. The deepest shaft, which is on the contact between a basic syenite dike and the pre-Cambrian granite, is reported to be 70 feet deep. In 1911, Mr. T. N. Hubbard had driven a tunnel 250 feet on this contact, on the Mocking Bird claim, following a narrow vein all the way. The vein varies in width from an inch to 10 inches but, where seen, is mostly less than five inches wide. The most abundant vein mineral is quartz; this is partly massive, but there are many well formed crystals projecting into small vugs. Almost throughout the 250 feet were frequent patches of good galena which reached across the narrow vein, beside a little chalcopyrite and pyrite. In small oxidized patches may be seen malachite, limonite, and a little well crystallized calamine.

Still farther south the Bay State and Independence tunnels have cut a dike similar to the dike mentioned above, if not the same dike. Two or three tons of ore were lying on the platform at the upper tunnel which was caved when visited. The ore is principally galena with a little pyrite in vein quartz. Small patches of a thin yellow coating on the galena and quartz are probably of silver bromide or chlorobromide.

PROSPECTS AND DEVELOPMENTS IN TAYLOR GULCH

Exchequer.—A shaft was sunk on the Exchequer claim to a considerable depth in mineralized limestone in what would appear to be favorable ground, but no payable ore was found. Material on the dump indicates that a large body of limonite is present. A porphyry dike was cut in the shaft, and is probably the same dike as that with which the ores of the Major and Shamrock are associated.

Jewell tunnel.—The Jewell Tunnel & Mining Company holds a large group of claims west of Taylor Gulch. This group includes several of the old small producers as well as the Mountain Chief and the New York mines already described. A large tunnel is being driven from near the head of the gulch toward Taylor Mountain to develop the ground held by the company. This tunnel has not yet uncovered any ore, though it has been driven about 1,000 feet. Excepting one drift toward the north, no prospecting has been done at the sides of the tunnel. The tunnel is equipped with motor, fan, air compressor, and machine drill.

Page tunnel.—This tunnel was driven about 1,300 feet westward across the steeply-dipping sediments for the purpose of opening the Ben Hill lead about 400 feet below the bottom of the shaft. Drifts have been run parallel to the bedding 200 or 300 feet, both north and south of the tunnel, in brecciated limestone, but ore in payable quantity was not found. Much of the country rock through which the tunnel runs is baked shale.

MINES OF CREE CAMP

SONG BIRD MINE

Attention was first drawn to this part of the district by the discovery of rich silver ore in the Song Bird in 1878. The deposit was in the limestone above the "parting quartzite" in a zone of local faulting. Although the mine was a producer of good ore for a short time no figures are available as to output. Considerable prospecting was done in the vicinity but results were generally unsatisfactory.

CLINTON MINE

The Clinton mine on the northwest slope of Missouri Hill was first opened in the early eighties but lay idle for a number of years. During 1901 to 1904 it was operated, when, according to Mr. A. B. Brewington, it produced about $12,000 worth of ore. The best ore is said to have been associated with garnet. The values were in silver, gold, copper, and lead. The manganese content was sufficiently high to secure a reduction in treatment charges.

The ore occurs in northward-dipping shoots in the limestone six or eight feet from the granite. One shoot carried ore practically from the surface to a depth of 300 feet, below which it was not worked. The greatest width of this shoot was eight or nine feet but at this point it did not carry values high enough to pay for the necessarily long haul. Were the mine nearer the railroad it is probable that further work would have been done before this time.

MINES OF MIDDLE FORK AND TRIBUTARIES

In the Middle Fork valley only two mines, the Mason and the Moose, are known by the writer to have produced ore since the survey of the district was begun. Development work, however, has been done in these years on a number of properties.

MOOSE MINE

The Moose mine, which is just below the crest of the Sawatch Range, in the quartz monzonite porphyry, has been worked through two short tunnels. When the mine was visited in 1910 the upper tunnel was filled with ice, but work was being done in the lower tunnel. This tunnel had been driven south 220 feet, and from it a crosscut had been driven west about 50 feet. Ore had been stoped out a few feet below the tunnel level.

About 40 feet south of the portal a narrow northward-dipping dike-like mass of fine-grained, much decomposed porphyry was crosscut by the tunnel. This porphyry seems to carry no megascopic quartz, and may be an inclusion of quartz latite porphyry picked up by the quartz monzonite porphyry or an intrusion in the latter rock. Above the fine-grained porphyry is a vein about three feet wide. The vein-filling is principally quartz, but at one side was a streak of ore about eight inches wide. The ore was chiefly galena interbanded with quartz. At the lower contact of the fine-grained porphyry with the quartz monzonite porphyry was a streak of ore a few inches wide, which contained narrow intersecting veinlets of galena and pyrite penetrating the fine-grained porphyry. An average sample, including rock and metallic minerals, yielded on assay 1.34 ounces gold and 93.9 ounces silver per ton; no lead assay was made.

About 85 feet west of the tunnel is a vertical quartz vein striking due north and about four feet wide. On account of the large quantity of talus this vein can be traced only a few yards on the surface. A sample from the surface of the vein yielded on assay only a trace of gold and 2.0 ounces silver per ton. It is reported that from this vein, where opened by the upper tunnel, three carloads of ore were shipped in the eighties which ran about

$165.00 per ton after paying freight and treatment charges as well as transportation. The ore was packed on burros to the road below. Several small shipments in recent years have been made by leasers who are prevented from working more than a few months each year by the snow on this slope. The ore shipped in 1909 is reported to have run about $50.00 per ton.

MASON MINE

This mine, according to the manager, Dr. Finla McClure, has produced about $75,000 worth of ore. The greater part of the production was in the eighties, but in recent years a few carloads of ore have been shipped from the mine each summer.

The Mason is about a quarter of a mile south of the Moose and but a short distance below the crest of the range. It has been worked through a shaft and a tunnel. A small part of the mine, mostly below the tunnel level, was accessible in 1910. From the tunnel level a winze has been sunk 75 feet and drifts run east and west of the winze. A second winze, from one of these drifts had been sunk 22 feet.

In these lower workings the ore was at the contact between volcanic breccia and the Paleozoic sediments. The sediments are chiefly indurated shale, siliceous dolomite, and calcareous sandstone. The ore, which is chiefly oxidized, is generally black because of the high content of oxide of manganese. Both hard psilomelane and an earthy variety of manganese oxide are present. A little galena may be seen. The ore is pockety; bunches vary from a few inches to several feet in width. Much of the ore is practically free from rock material, but in places the metallic minerals from the matrix of a breccia whose fragments are chiefly volcanic breccia. Owing to the presence of much manganese oxide the rock may be black several feet from the ore. Large blocks of practically pure psilomelane, evidently from another part of the mine, were lying on the dump.

The ore mined in 1910 was said to run about .03 ounces gold and 13 to 30 ounces silver per ton, 27 per cent manganese, and 8 to 20 per cent iron. The ore is packed on burros to the creek below and thence hauled by wagon to the railroad.

EMMA STRADLEY MINE

According to the report of the Director of the Mint the Emma Stradley produced $636.00 worth of ore in 1887, the chief values being in silver. But little work has been done on the property in the past 25 years. In 1910 the mine was under lease to H. A. Meyers, who was driving a tunnel to cut the lead that had been opened in the upper tunnel. The principal works which are in the quartz latite porphyry, are: a tunnel 750 feet long; one drift from the tunnel, 200 feet long; and a winze, sunk from the drift, 90 feet deep. It is reported that two 10-ton carloads of ore were taken from the winze.

GULCH MINE

According to the reports of the Director of the Mint, the Gulch mine, in 1887-1889, produced gold and silver having a coinage value of $2,380 and $13,054, respectively. The mine was worked through two tunnels which were driven mainly in quartz latite porphyry. A third tunnel was driven a considerable distance, but is reported not to have reached the lead.

GOLDEN AGE MINE

A tunnel about 550 feet long in the quartz monzonite and a drift about 40 feet long constituted the developments of this property when visited in 1909. The drift is on a shear zone which shows gouge and pyrite in the roof. Mineralization extends through a width of about three feet. A small amount of galena was found in the breast of the tunnel in the country rock. Pyritization was frequently seen in the tunnel.

This property has produced two carloads of ore. According to Mr. Henry L. Acker, the better car netted $30.00 a ton after paying freight and treatment charges.

COLUMBUS MINE

This mine was worked through tunnels on several levels all of which are now caved except the lowest. Bad air in this one prevented an examination by the field party. The workings are, in the main, just east of the eruptive contact between the quartz monzonite and metamorphosed sedimentary rocks. Much vein quartz and a considerable quantity of sulphides of iron, copper, lead, and zinc were seen. Water issuing from the tunnels carries in solution an appreciable amount of copper salts. The following is taken from the Report of E. Le Neve Foster, State Geologist:[1]

The Columbus mine is situated about 12,000 feet above sea level on the southern slope of Taylor Mountain. Its workings consist of shafts

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[1] Report of E. Le Neve Foster, State Geologist. 1884. pp. 30-32. Mr. Foster credits the account to Mr. F. G. Bulkley.

and tunnels and develop a true fissure vein to a depth of 300 feet, and horizontally 1,100 feet. The outcroppings of the vein may be clearly traced upon the surface for this entire distance, with almost unbroken continuity, commencing at its southern extremity in a deep depression in the side of the mountain, and following very crookedly a mean northeasterly course up an ascent of 30°, where it is finally hidden under surface debris. * * *

The matrix of the vein is quartz from wall to wall. The clay selvage usually accompanying the walls of fissure veins is in this instance more often lacking, though occasionally present, with a thickness of one-fourth to two inches. For the first 200 feet of depth the quartz is irregularly banded, composed in a great measure of agglomerations of coarse amorphous [xenomorphic?] crystals, or spongy from the decomposition of pyrite, and deep brown in color from the presence of much iron oxide. The whole width of the vein, from 6 to 20 feet, is productive of good value in silver, which occurs as a sulphuret and contains also varying quantities of gold. At the depth of 200 feet the vein material changes abruptly to a pure white quartz, containing large quantities of pyrite and sphalerite intimately associated, in very perfectly shaped crystals of one-twentieth to one-half inch in diameter. Copper is also found; native, in spongy masses and as a thin coating of blue or green carbonate, while silver is less widely distributed through the thickness of the vein, being confined to certain localities rich in iron and zinc sulphurets. These conditions remain constant in the lowest depths of exploration. A spur or branch of the vein has its apex in the granite [quartz monzonite] to the west and joins the main vein at a depth of 200 feet. Its strike is due north, and its dip about 70° to the east. The vein material here is productive of small quantities of silver, and consists of a compact brownish quartz. No influence seems to be exerted upon the productiveness of the vein by the junction of this spur, either in quantity or quality of the ore.

The mine was operated for several years, the ores being concentrated in a mill on Middle Fork. The mill has since been sold and removed, and the aerial tramway which connected it with the mine is no longer standing. The men who owned the mine when it was operating are now dead, and no record of the output is known to exist. Mr. W. K. Jewett, the present owner, writes: "Tradition says that its gross production during the period of its operation was approximately $300,000, the values being mainly silver and copper."

BRIGHTON MINE

This mine, which is now filled with water and ice, is in the quartz monzonite area. Material on the dump is similar to that of the Columbus. It is not improbable that the ore was in a fissure vein which intersects the Columbus vein. The report of the Director of the Mint, for 1881, states that at that time the mine was opened by a shaft 100 feet deep with drifts 30 feet each way from the bottom of the shaft, all in ore which milled $40.00 a ton, net, and that about 100 tons had been shipped.

DARLING MINE

This property is reported to have produced one carload of ore from a shaft 26 feet deep on a lead in the quartz monzonite. The shaft was full of ice when seen by the writer, but a small quantity of good galena remained on the platform. A tunnel was being driven to cut the ore at a greater depth.

UNCLE SAM MINE

The Uncle Sam in Hoffman Park is reported to have been operated while Maysville was the terminus of the railroad. The workings are now inaccessible but it is probable that the ore was either in the quartz monzonite porphyry or at the contact between the porphyry and the quartz monzonite on the east.

ALPHA AND BETA

An output of 20 tons of silver-lead ore is reported from these two claims in Kangaroo Gulch. The Maverick tunnel below, through which it is proposed to work these leads, has been driven 650 feet.

OTHER MINES AND PROSPECTS

D'Byron group.—This group comprises several claims on the slopes of Monumental Mountain. Several short tunnels have been driven on quartz veins in the quartz monzonite porphyry; these veins carry irregularly-distributed ore. One tunnel about 150 feet long, not far north of the Moose mine, is reported to have produced one carload of ore.

Mohammed.—The Mohammed tunnel was visited in 1910 just as work was suspended because of caving and a great flow of water at the breast. A second attempt to get through the bad ground in a crosscut north of the main tunnel had been unsuccessful. Besides the main tunnel 700 feet long, a few drifts and crosscuts, aggregating several hundred feet in length, were accessible.

The main tunnel was driven N. 70° E. through the Etna porphyry for most of the distance. The rock for the last 60 or 70 feet, including the badly broken ground at the breast, is quartz latite porphyry. The presence of much gouge as well as slickensiding at the contact between the two kinds of porphyry indicates faulting, but this fault is probably along the original contact. A winze said to be 25 feet deep had been sunk in one of the drifts about 100 feet south of the tunnel. It was impossible to see the ore at the bottom of the winze on account of water, but 20 sacks of good galena, seen outside, had been taken from this winze. In the end of the drift a quartz vein carried a streak of galena two or three inches wide. The porphyry on both sides of the vein is much decomposed. Mineralization, chiefly pyrite, could be seen in much of the rock on the dump.

Macedonian.—The Macedonian tunnel has been driven eastward about 1,300 feet with the intention of cutting a lead that was opened at the surface. The tunnel starts in the Etna quartz monzonite porphyry, but enters quartz latite porphyry at about 900 feet from the portal. In this tunnel, also, there is evidence of faulting along the contact between the two kinds of porphyry, though this is not the same contact as that crossed by the Mohammed tunnel. Near the breast a very narrow vein of pyrite was crossed by the tunnel. The lead opened in the shallow shaft, several hundred feet above, is now inaccessible, but it is reported that a small quantity of good ore was taken out many years ago.

Tweed group.—This group comprises seven claims, which cover much of the ground on both sides of the creek south of Mount Etna. Several tunnels have been driven north of the creek in the quartz monzonite. Some good galena, with sphalerite and copper-bearing pyrite, may be seen on the dumps. Specimens exhibit evidence of one or more veins at least several inches thick. At the dump of a long tunnel south of the creek, in quartz monzonite porphyry, some zinc blende with galena, pyrite, and vein quartz may be seen. Still farther south prospects in the pre-Cambrian granite, near the quartz monzonite, are reported to have uncovered very thin seams of high grade gold ore. In this vicinity there is much iron oxide stain.

Hercules.—The Hercules tunnel, in Hoffman Park, has been driven east in the quartz monzonite 600 feet or more. A narrow vein in a drift carries galena and chalcocite, with a small amount of chalcopyrite, but no payable ore has been reported in this tunnel.

Prospects at Boss Lake.—Considerable prospecting has been done near Boss Lake at or near the surface. Pyrite is abundant east and north of the lake. A sample taken from a one-foot vein about 500 feet northeast of the lake and within 10 feet of the surface yielded on assay .26 ounces gold per ton and a trace of silver. In a shaft just east of the lake a streak of mineralized dolomite four or five feet wide was found about four feet below the surface. This streak contains sphalerite, galena, and pyrite. A sample assayed, gave a trace of gold and 2.25 ounces silver per ton, 8.52 per cent lead, and 23.8 per cent zinc. On the east side of the lake, also, several tons of magnetite have been taken from a vein two or three feet wide, at the water's edge. A few tons of ore were taken from a tunnel in the fault north of the lake. The work was evidently done many years ago and the tunnel could not be entered in 1910, but a sample of limonitic ore from the dump assayed .32 ounces gold and .92 ounces silver per ton and 12.10 per cent lead. It evidently contains a high percentage of excess iron.

MINES AND PROSPECTS OF NORTH FORK AND BROWNS GULCH

In the late seventies and early eighties there was much activity in the North Fork valley and a small quantity of silver-lead ore was mined. For many years past, however, the mining in this valley has been intermittent, and only a few ore shipments have been made. In the summer of 1911 there were 20 men, or more, working in the valley, and probably a less number in 1910. In July, 1912, only assessment work on unpatented claims was being done.

MICHIGAN GROUP

This group contains nine patented claims, several of which have produced ore. The total output is reported to be about 200 tons. Most of the ore came from a short tunnel in the Pomeroy quartz monzonite, just under the divide between North Fork and Grizzly Gulch. This tunnel and others on the Michigan claims are now caved, but the occurrence of the ore in a fissure vein is inferred from the association of galena with vein quartz, seen in specimens on the dump. A short tunnel on the May Queen claim has opened a vein about a foot wide, from which ore has been shipped. The ore, of which several hundred pounds lay on the dump in 1910, is zinc blende and galena with pyrite and quartz. It would doubtless concentrate well.

MINES OF THE NORTH FORK POWER & MINES COMPANY

Pride of the West.—The Pride of the West tunnel was driven many years ago in the Pomeroy quartz monzonite a distance of nearly 1,300 feet. Several north-south veins of low grade ore were crosscut by the tunnel, but no ore was shipped by the original owners. In 1911 the North Fork Power & Mines Company was drifting on one of the leads and concentrating the ore in the company's mill at Shavano.

The lead which was being mined is about 600 feet west of the portal of the tunnel. At this point the tunnel is about 250 feet below the surface. In August, when seen, the drift was about 100 feet long. The lead is about five feet wide and dips westward 70°. It is made up of many ore-bearing veins between which is porphyry, mineralized and partly decomposed. The veins vary in width from a millimeter, or less, to 20 inches. Some of the narrowest veins are practically filled with metallic minerals, but the wider ones carry more quartz than metallic minerals. The determinable metallic minerals are galena, blende, and pyrite. The microscope shows these minerals disseminated through the porphyry in appreciable quantity. The porphyry shows no distinct contact with the quartz monzonite and may be a facies of the latter rock. While the veins carry the best ore all the ground broken was run through the mill.

A trial shipment of concentrates gave 36.9 ounces silver per ton, 47.1 per cent lead, and 17.7 per cent iron. Zinc concentrates were made which assayed 26.5 per cent zinc. In general, assays of the lead concentrates showed about one ounce of silver for each per cent of lead, but the zinc concentrates carried only one ounce of silver to each 10 per cent of zinc.

Little Orphan Annie.—Only a small amount of work has been done on this claim, where a lead about three feet wide was exposed at the surface. The lead strikes a little west of north and stands nearly vertical. It is apparently at the contact between the Pomeroy quartz monzonite and a coarse porphyry similar to that in the Pride of the West mine. The lead contains several nearly parallel fissure veins filled with quartz and metallic sulphides. Galena is the principal metallic mineral but chalcopyrite has also been reported. A small shipment returned 47.6 ounces silver per ton and 24 per cent lead. It is possible that the Little Orphan Annie vein is the same as that opened on the May Queen.

Condor mine.—A small shoot of good galena and zinc blende was opened in a short tunnel on the Condor claim. The ore in the tunnel is about three feet thick and is reported to have extended to the surface 40 feet above. This is at the contact between the quartz monzonite porphyry and Princeton quartz monzonite. A lower tunnel was driven to cut this shoot which apparently does not extend to the level of the lower tunnel or does not hold a uniform dip. However, the lower tunnel did not follow the contact, and there is a possibility of finding the ore by crosscutting.

Near the west side of the wide dike of porphyry a small vein of good galena, having a maximum width of three inches, was found.

TOM PAYNE MINE

The Tom Payne is one of a group of claims (North Pole group) owned by the Peerless Mining & Milling Company. This group is on Cyclone Mountain and chiefly on the east slope. The Tom Payne is reported to have produced one carload of ore. The workings include shallow shafts and short tunnels with one tunnel said to be over 1,000 feet long. Zinc blende and pyrite with vein quartz may be seen in the ore, of which several tons lay on the dump of the long tunnel in 1910. Higher on the mountain the dumps show galena and cerussite with vein quartz in altered andesite.

OTHER MINES AND PROSPECTS

The Tomcat group of claims on the top and southwest slope of Carbonate Mountain was being prospected by a force of several men in 1910. Near the top of the mountain specimens from a shallow shaft showed iron-stained and copper-stained galena in vein quartz. A tunnel was being driven in the andesite on the southwest slope, to cut the lead at a depth of about 300 feet.

The Uncle Sam Mining & Reduction Company has driven a long tunnel on or near the contact between the andesite and Pomeroy quartz monzonite near the head of Cyclone Creek. Through part of its course the tunnel follows a narrow quartz vein which carries galena and pyrite. The wall rock also carries an appreciable quantity of these sulphides.

Near the head of North Fork, south of the Pride of the West tunnel, are several shallow shafts and open cuts on veins from a few inches to four feet wide. Ore is reported to have been shipped from at least one of these veins. The vein-filling is quartz with pyrite and galena.

Good galena and blende with quartz is common on the dumps of shallow workings near the head of Grizzly and Pomeroy gulches in the Chalk Creek district. Ore has evidently been hauled away from a few of the prospects.

About half a mile north-northwest of Missouri Hill, a tunnel is being driven by L. F. Anderson, at the contact between limestone and a porphyry dike. In 1910 the tunnel was in about 60 feet. Severel hundred pounds of copper-bearing pyrite lay on the dump.

A molybdenum-bearing vein outcrops north of Browns Creek, just outside of the area mapped. The vein, which is a filled fissure, strikes about N. 65° E. and stands nearly vertical. The vein-filling is principally quartz, with patches of molybdenum minerals. Although the vein proper is only about three feet wide, the wall rock (Pomeroy quartz monzonite) contains a considerable percentage of molybdenum minerals and pyrite. Near the surface the vein-filling and wall rock are more or less coated with earthy, yellow molybdite, or molybdic ocher. However, a few feet down, molybdenite is found in patches in the quartz and in veinlets in the wall rock. The wall rock contains, also, numerous small crystals of pyrite. The thickest veinlets seen are about an eighth of an inch across and the individual crystals of molybdenite are small.

The vein has been prospected by a short tunnel and shaft, but no shipments have been made except for tests. An average sample of the ore assayed by H. F. Watts gave 2.12 per cent of molybdenum.

MISCELLANEOUS MINES AND PROSPECTS

A few small mines and a few prospects not within the areas previously specified are deserving of mention. Nearly all are in the pre-Cambrian rocks.

HIGHLAND

A shaft has been sunk on the Highland claim, east of Como Gulch, on a vein reported to vary from 3 to 18 inches in thickness. A small quantity of good galena has been taken from the shaft. The rock in the vicinity of the Highland is pegmatite with subordinate gneiss. A tunnel lower on the slope had not cut the lead in 1910.

PAYMASTER GROUP

The Paymaster group comprises a number of claims south of the South Arkansas, about a mile west of Maysville. Several small shipments of silver-lead ore have been made from the group. Some of the ore is reported to carry gold. In 1910 there were four tunnels 125 to 150 feet long, on the property; a fifth tunnel was about 300 feet long. All the tunnels are well timbered. The veins, which are in fractured gneiss, are from a few inches to two feet in thickness and trend southward. Though no large body of ore had been found when the property was visited, a good grade of galena was obtainable by careful sorting. West and north of the tunnels there is much pegmatite which commonly shows a copper stain. In places a little chalcocite and chalcopyrite may be seen in the pegmatite.

BON TON

The Bon Ton property includes a shaft and two or more tunnels. Evidently ore was taken from a shaft which is now caved. One of the tunnels, which was about 200 feet long in 1909, showed a vein in the breast which carried zinc blende with a little pyrite. The vein was about eight inches wide, where seen, and was in part a partial replacement of the wall rock which is garnetiferous gneiss. Several sacks of good sphalerite were ready for shipment.

LOST BASIN GROUP

This group includes 13 unpatented claims near the head of Lost Creek. In 1910 a tunnel was being driven northward in quartz diorite and gneiss to cut a lead that had been opened at the surface. The tunnel, when seen was 600 feet long. The shallow shaft which had been sunk on the lead was caved, but material on the dump indicates a strong vein. Large chunks of limonite which had evidently been formed by the oxidation of pyrite, as well as quartz crystals several inches thick and up to a foot in length, were found. The country rock is gneiss.

SERIES JUNCTION GROUP

This group is a short distance east of the Lost Basin group and includes three unpatented claims. A shaft, which was caved when visited, had been sunk on a north-south vein that was 6 to

10 inches wide at the surface. The wall rock is granite. Several hundreds pounds of iron-stained and copper-stained quartzose ore lay on the dump. A tunnel was being driven to cut the vein at a greater depth.

OTHER PROSPECTS

About a mile south of the Bon Ton there is much mineralization of the gneiss and associated pegmatite. A small quantity of ore has been taken from a few shallow prospects. The best ore seen is galena associated with amphibole and garnet, but most of the ore shows no mineral except malachite which is present as a thin coating or stain. A little calamine was seen.

The Shavano Mining & Milling Company has been driving a tunnel in the gneiss, about half a mile south of the top of Shavano Mountain, at an altitude of nearly 13,500 feet, with the intention of cutting a lead which was opened on the surface in the saddle above. It is reported that a shipment, from the surface workings, of 48 sacks, returned $40.00 per ton in gold.

A few tons of ore, reported to carry 20 ounces gold per ton, were shipped by Dr. Finla McClure from a tunnel in pegmatite, about a mile west of Maysville.

PLACER MINING

Free gold is reported to have been found, many years ago, in the ravines and gulches on the slopes of Shavano Mountain. Placer mining was attempted in one or two localities, but the water supply was inadequate for washing.

MILLING

There is only one concentrating mill in the district—that of the North Fork Power & Mines Company, at Shavano. This mill is modern, but small, having a capacity of 25 to 30 tons per 24 hours. Though the efficiency of the mill seems to have been demonstrated in a run of several weeks, in 1911, the expense of hauling low-grade ore three miles over a rough wagon road is too great to allow much profit.

The mill is run by steam power. The ore is crushed by a jaw-crusher to which it is automatically fed. The ore from the crusher is further reduced by rolls, is screened, and concentrated on Wilfley tables. A good separation of the zinc blende and galena is effected. A trial shipment to the smelter, of lead concentrates, in 1911, gave 39.9 ounces silver per ton, 47.1 per cent lead, 17.7

per cent iron, and 2.0 per cent silica. The proportion of silver to lead is reported to be higher in most of the ore mined, but in this shipment considerable material had been taken from the vein at the surface where the silver content is low.

When the Columbus mine was producing, most of the ore was concentrated in a mill about a mile above Garfield on Middle Fork. The Columbus mill was sold and removed after the mine was shut down.

STONE

LIMESTONE

The Ohio & Colorado Smelting & Refining Company owns a quarry at Garfield from which limestone, for flux, is shipped to the company's smelter at Salida. Ten to twenty-five men are employed at the quarry which is operated almost continuously.

The Garfield quarry, under lease to L. W. Hubbard, is operated several months each year. About ten men are employed when the quarry is working regularly. The limestone is largely used for flux by the smelters at Leadville and Salida; in recent years it has also been extensively used in sugar refining by the factories of the Arkansas valley. The rock of these quarries is the blue crystalline limestone of the Ouray formation and is nearly pure calcium carbonate. (See analyses in the chapter on Paleozoic sediments.)

BUILDING AND MONUMENTAL STONE AND STONE FOR INTERIOR WORK

MARBLE

There is a large amount of marble in Taylor Gulch and in the vicinity of Cree Camp, which will probably be valuable when the better-known supply in other localities is exhausted, if not before. A small quantity at the head of Taylor Gulch is blue, but most of the marble is pure white. The chief objectionable features are the general coarseness of texture and, at the surface, the frequency of joint planes. Wollastonite, diopside, and serpentine are locally seen in patches, but much of the marble is entirely free from these silicates.

A prospect near the Exchequer shaft is said to have supplied a small quantity of marble for the Colorado capitol. The largest blocks seen on the dump were about six feet long. The marble is pure white and practically free from silicates.

ONYX MARBLE

Onyx marble of good quality was taken from a shaft on or near the Bill Ingersoll claim. Whether or not there is sufficient marble here to warrant further development is not known.

GRANITE

The name granite is here used in the commercial sense to include rocks closely related to granite in texture and composition. There is no apparent reason why the Princeton quartz monzonite would not make a good building stone. The texture, composition, and color, are suitable; joint-planes are not commonly so closely spaced as to cause waste in quarrying. A small amount of this rock has been quarried on Chalk Creek. Both varieties of quartz diorite would make good monumental stone; they would probably dress well, take a good polish, show lettering distinctly, and have an attractive color. It is possible that frequency of joint-planes would be a disadvantage. The Etna quartz monzonite porphyry could be readily worked and would be an attractive stone for monumental purposes. All the rocks mentioned here are some distance from the railroad.

QUARTZITE

The dark blue quartzite at the base of the Garfield formation has a very attractive color and should take a high polish. Without doubt it would make a suitable monumental stone where large dimensions are not required. This quartzite is found within a few feet of the railway. It can be readily examined east of the Lilly tram terminal, at a prospect near the creek.

CHAPTER XI

ECONOMIC GEOLOGY OF THE TOMICHI DISTRICT

HISTORY OF MINING

Ore was first discovered in the Tomichi district in 1879; the North Star, Nest Egg, Denver City, David H., Legal Tender, Lewiston, and probably Eureka claims were located the same year. Before the fall of 1882, the Lilly, Silver Cord, Annie Hudson, Erie, Victor (originally Beta), and Defiance claims were located; several had already produced payable ore. Later discoveries on other claims were made, and from 1880 to 1884 mining and prospecting were vigorously carried on. From 1885 to 1893 the district was fairly prosperous, but since 1893 only a few mines have produced ore in considerable quantity.

Few, if any mines were regular shippers for many years. Two or three years of heavy production by a mine were likely to be followed by a period of inactivity for that mine, while another, previously unproductive, would become a heavy producer. Since 1910, when the Survey began work in the district, considerable development work has been done on a few properties, and ore has been shipped from the Morning Star, Spar Copper, Erie, and West Point mines.

The isolation of the district has been a severe handicap. Only rich ore could be profitably hauled by wagon to Sargents and shipped by rail over the range to the smelters at Pueblo and Denver. Two small smelters were erected south of Whitepine. One is said to have been operated intermittently for several years, the other about three months. A large mill south of Whitepine seems not to have treated much ore. Expensive litigation between mine owners and a lack of co-operation appear to have been contributing causes of the decline of mining, and when the known high-grade ore bodies failed there was but little tendency to spend money in development work.

PRODUCTION

The total output of the district is unknown. The Mint reports give the production of several mines for single years; these figures are quoted in the section on the description of mines. The output of many of the largest producers is not given in the Mint reports, and it is improbable that the total production of any single mine is there recorded.

WATER SUPPLY AND TIMBER

Tomichi Creek carries abundant water for any needs of the district, but the flow in most of the tributary streams is small except during the rainy seasons. Timber for mining purposes is abundant, though there is but little in the immediate vicinity of many of the mines.

GROUND WATER

It is said that it was difficult to keep many of the former producing mines well drained, and during recent summers the level of the water was high in many unused shafts. During the summers of 1910 and 1911, though the rainfall was heavy, the small amount of water removed from the Morning Star mine—the deepest now operating—was hoisted in the ore bucket.

CHARACTER OF THE ORES

In metallic content and chemical and mineral composition, the ores of the Tomichi district present a considerable variety. Metals that have been produced in commercial quantity, are: gold, silver, lead, zinc, copper, and iron. By far the most important metals produced by the largest mines in former years are silver and lead. The silver-lead ores that are now being mined are chiefly sulphide ores, but most of the mines produced lead carbonate from near the surface. Limestone and dolomite constitute the principal gangue of the largest known ore bodies, in the sedimentary rocks. The chief gangue minerals of the fissure veins are quartz and pyrite. The iron ore bodies are of magnetite and limonite.

TENOR OF THE ORES

There are no available data by means of which the average value of the ores can be determined. The range however, is great, and it is probable that most of the ore from near the surface was of high grade.

Part of the ore of the Lilly mine is said to have carried as high as 200 ounces in silver per ton, and much that carries about $1.00 in gold and 25 ounces silver per ton and 2 to 5 per cent copper was thrown on the dump. The one carload shipped from the Silver Cord mine ran about 85 ounces silver per ton and 40 per cent lead. The Legal Tender is reported to have produced much lead carbonate ore that carried 40 ounces silver to the ton. The best ore of the Lewiston is reported to have yielded about $800 to $1,000 per ton in gold and silver. The Fort Scott ores averaged $50 to $100 a ton in gold, silver, and lead. The Mint report for 1883 states that the North Star ore at 110 to 130 feet was chiefly galena averaging 110 ounces silver per ton and 50 per cent lead. The same authority for 1881 states that an ore body of the Annie Hudson ran 80 ounces silver per ton. The Victor ore is reported to have averaged $62 per ton in silver and lead. An assay of the Morning Star ore showed .14 ounces gold and 19.10 ounces silver per ton, 22.7 per cent lead, and 45 per cent zinc. The high-grade ore of the Denver City mine is reported to have had a value of about $200 per ton.

Doubtless much of the ore was of lower grade than the examples mentioned, but very low-grade ore could not be profitably hauled 12 to 15 miles by wagon to Sargents, and shipped to the smelters at Pueblo and Denver. As a result there is probably remaining much ore which, in districts more favorably situated, would pay well. It is known that there is much low-grade ore in the undeveloped fissure veins.

MINERALOGY OF THE ORES

All the metallic minerals known to be present in the Tomichi district are included in this section, though some of them are not found in sufficient quantity to be considered ores. The few gangue minerals known are also included. The metallic minerals are listed alphabetically under the name of the most important metal which each contains, and notes on the occurrence of each are given. For the convenience of miners and prospectors in the district who may not have at hand a text-book of mineralogy, the percentage of the most important metal in each mineral is given.

CADMIUM

Greenockite, cadmium sulphide, CdS—cadmium 77.7 per cent. Greenockite occurs as a yellow coating on the sphaleritic ore of the Bill Short mine and of a prospect a few hundred feet east of the portal of the Bill Short tunnel. In order to determine the amount of cadmium present in the sphalerite itself a sample was selected that showed practically no greenockite. This sample—sphalerite with galena, chalcopyrite, and quartz—assayed by Mr. Watts, carried 32.65 per cent zinc and .24 per cent cadmium.

COPPER

Azurite, basic cupric carbonate, $2CuCO_3.Cu(OH)_2$—copper 55.3 per cent. Azurite was found in very small quantity in specimens from the Victor mine and from near the Iron King mine.

Chalcocite, cuprous sulphide, Cu_2S—copper 79.8 per cent. Chalcocite forms a thin, black, sooty coating on pyrite in the Princeton tunnel.

Chalcopyrite, copper-iron sulphide, $CuFeS_2$—copper 34.5 per cent. Chalcopyrite, in small quantity, associated with zinc blende, galena, and pyrite was found at several mines. It occurs in the fissure veins in the granite and quartz monzonite, and in the replacement deposits in limestone.

Copper, native. Native copper is said to have been found in the Morning Glim tunnel.

Cuprite, cuprous oxide, Cu_2O—copper 88.8 per cent. A small pocket of this mineral near the Iron King mine is reported to have yielded two tons of rich copper ore.

Enargite, copper sulpharsenate, Cu_3AsS_4—copper 48.3 per cent. This mineral was found associated with pyrite in a specimen from the Morning Glim tunnel.

Malachite, basic cupric carbonate, $CuCo_3.Cu(OH)_2$—copper 57.54 per cent. The green carbonate of copper is found in considerable quantity in veinlets and impregnations on Copper Hill, particularly on the northwest slope. Near the Iron King mine and at the Denver City mine small specimens of good malachite were found. As a stain it is common on surface rock and ore specimens of several mines and prospects.

Tennantite, $Cu_8As_2S_7$—and *tetrahedrite,* $Cu_8Sb_2S_7$. Tetrahedrite, or gray copper, is reported from the Spar Copper, Lilly, David H. and Victor mines. A specimen from the Victor mine, showing by a qualitative test an appreciable quantity of arsenic, was submitted for a quantitative determination of arsenic and antimony. This specimen, which contained considerable galena, carried 3.60 per cent antimony and 2.87 per cent arsenic, as determined by Mr. Watts. The molecular ratio of the contained antimony to arsenic is therefore approximately 30 to 38. This specimen is hence tennantite grading toward tetrahedrite.

GOLD

Native gold is said to have been present in the ores of the Lewiston and Pet mines. Gold values are found in the sulphide ores of the Spar Copper, Morning Star, and Lilly mines. Several quartz veins in the quartz monzonite carry gold near the surface.

IRON

Hematite, ferric oxide, Fe_2O_3—iron 70 per cent. No hematite was seen with the ores, but a small amount of specular hematite has been developed by contact metamorphism about half a mile west of Granite Mountain.

Limonite, ferric oxide with water, $2Fe_2O_3.3H_2O$—iron 59.8 per cent. Brown limonite is found as gossan above many of the ore bodies. It is also found associated with magnetite as a replacement in the vicinity of the Iron King mine, on Galena Creek about a mile southeast of the Iron King, and in the sediments near the quartz monzonite three-fourths of a mile west-northwest of Granite Mountain. It is very common southeast of Lake Hill where it is frequently iridescent. On the northeast slope of Lake Hill, limonite is found as pseudomorphs after pyrite, in cubes from one-fourth inch to two inches on an edge. As bog ore limonite is found near Tomichi Creek, about a mile and a half above Whitepine. The deposit, which is about three feet thick, is porous, the limonite having replaced vegetable material.

Magnetite, a compound of ferrous oxide and ferric oxide, $FeO.Fe_2O_3$—iron 72.4 per cent. Magnetite is found at several places in the sedimentary rocks not far from the quartz monzonite and, in one locality, in quantity sufficient to constitute a workable iron-ore body that has been opened up by the Iron King mine. Here the magnetite is associated with serpentine and tremolite. Not far from the mine and elsewhere, limonite is commonly associated with the magnetite.

Pyrite, iron disulphide, FeS_2—iron 46.6 per cent. Pyrite is common in all the veins that carry sulphides and is also frequently found disseminated through the wall rock in the granite and quartz monzonite areas. Much of the pyrite is copper-bearing as shown by the green coating that specimens acquire when they are exposed to the weather.

Turgite, hydrous ferric oxide, $2Fe_2O_3.H_2O$—iron 66.2 per cent. Red, massive turgite is found in small quantity associated with limonite southeast of Lake Hill.

LEAD

Anglesite, lead sulphate, $PbSO_4$—lead 68.3 per cent. Anglesite was seen at a shaft near the top of Clover Mountain. This anglesite, though not transparent, is of good quality. It is said that considerable lead sulphate was produced by the Eureka mine.

Cerussite, lead carbonate, $PbCO_3$—lead 77.5 per cent. Both hard and soft lead carbonate were found in the oxidized zone in several of the mines of the sedimentary area. The carbonate commonly carried high silver values. The soft variety was admixed with more or less limonite. Hard, dark-gray crystallized cerussite from the Denver City mine was seen by the writer.

Galena, lead sulphide, PbS—lead 86.6 per cent. Coarsely crystallized galena is found in the deeper workings of nearly all the mines.

MANGANESE

Psilomelane, perhaps H_4MnO_5—manganese nearly 40 per cent. Psilomelane is found in the limestone a short distance above the granite, a few hundred feet southwest of the Breadwinner mine.

MOLYBDENUM

Molybdenite, molybdenum disulphide, MoS_2—molybdenum 60.0 per cent. This mineral was not seen in the course of the present survey, but it has been reported from a prospect near Tomichi.

SILVER

In addition to the two silver minerals named below, rich silver-bearing lead carbonate and galena have been found in several mines. Silver-bearing tetrahedrite has been reported from the Lilly, Spar Copper, David H., and Victor mines.

Silver, native, Ag. Native silver, associated with native gold, is said to have been found in considerable quantity in the high-grade ore of the Lewiston and Pet mines.

Stephanite, or *brittle silver,* silver sulphantimonite, Ag_5SbS_4—silver 68.5 per cent. Stephanite of good quality is found in the David H. mine.

ZINC

Calamine, hydrous zinc silicate, $H_2Zn_2SiO_5$—zinc 54.2 per cent. Colorless to black calamine is found in the Breadwinner, Denver City, and David H. mines. It is partly in groups of radiating crystals.

Smithsonite, zinc carbonate, $ZnCO_3$—zinc 52.2 per cent. This mineral, in earthy form and yellow to black in color, has been found in the Annie Hudson and Legal Tender mines.

Sphalerite, or *zinc blende,* zinc sulphide, ZnS—zinc 67 per cent. The ores of the Morning Star mine contain a large proportion of fine-grained sphalerite; the sphalerite of the West Point mine has a coarse grain, steel gray color, and metallic luster; that of the Erie mine has a coarse grain, brown color, and sub-metallic luster, the sphalerite of Robbins Gulch is coarse in texture and resinous in luster.

GANGUE AND NON-METALLIC VEIN MINERALS

Barite, or heavy spar, barium sulphate, $BaSO_4$. Barite is said to be present near the ores of the Lilly mine.

Calcite, calcium carbonate, $CaCO_3$. Vein calcite is found with some of the sulphide ores of the Victor mine. At the dump of a caved tunnel in the Etna porphyry on the south slope of Monumental Mountain may be seen considerable vein quartz and coarsely-crystallized calcite in blocks nearly a foot in diameter. It is hence inferred that the quartz and calcite are associated in a fissure vein. Calcite and fluorspar are associated in the vein of the Brittle Silver mine on the northwest slope of Brittle Silver Mountain. Limestone and dolomitic limestone form the walls of several ore deposits in the sedimentary rocks east of Whitepine.

Fluorite, or *fluorspar,* calcium fluoride, CaF_2. Green fluorspar is found in the Brittle Silver vein which extends southward through Central Mountain. In the Tomichi district the vein is about two feet wide; but a small part of the filling is fluorspar, while the greater part is quartz. Another north-south fissure vein a few yards east of Tomichi Pass is filled with fluorspar and quartz. The vein, which can be traced only a few hundred feet, varies from a few inches to three feet in width and is filled with fluorite and quartz.

Quartz, silica, SiO_2. Quartz is the principal filling of all the fissure veins.

Serpentine, $3MgO.2SiO_2.2H_2O$. Massive, gray to green serpentine is associated with magnetite in the Iron King iron mine.

Tremolite, $CaO.3MgO.4SiO_2$. Microcrystalline tremolite may be seen in thin sections of the serpentinous iron ore of the Iron King mine. The amount of observed tremolite is small, and it can scarcely be detected without the aid of a microscope. It is important only in its bearing on the origin of the ore.

CLASSES OF ORE DEPOSITS

The classes of ore deposits that have been recognized in the Tomichi district are:

1. Replacement ores in limestone and dolomite.
2. Contact deposits.
3. Fissure veins.
4. Bog iron ore.

REPLACEMENT DEPOSITS

There is little, if any, doubt that all the ore bodies hitherto found in the Paleozoic sediments are replacement deposits. A few, however, those of the North Star, Morning Star, and Victor mines, are in contact with a rhyolite porphyry dike, but it is not known that there is any genetic relation between the ores and the dike. Continuous shoots for at least 200 feet in length have been found in a few mines, but the history of most of the mines and the evident shallowness of the mine workings lead to the inference that much of the ore was in bunches. The deepest shaft in the district is said to be 365 feet deep.

The favorite localities or horizons of the replacement ore bodies are: (1) in and near the faults, (2) in the basal part of the Tomichi limestone, and (3) near the quartzite strata. In the vicinity of several mines the limestone has been changed to marble by contact metamorphism, and tremolite has been locally developed. Ore bodies in these positions approach in character or are identical with, the contact-metamorphic type described below.

CONTACT DEPOSITS

In addition to the silver-lead ores that are in contact with a porphyry dike, there is a body of magnetite near the northwest extremity of the Morning Glim fault that deserves mention. This magnetite is also in contact with a dike of rhyolite porphyry and associated with the ore are tremolite and serpentine. The iron-ore deposits were mapped by Harder and Ward in 1906 and a detailed description by Harder[1] was published in a bulletin of the U. S. Geological Survey. Harder says:

The principal deposits vary in thickness from 5 to 40 feet, and extend along the contact for a distance of several hundred yards. Beyond in either direction is merely a local staining and a few small veins. Ore occurs also in small bodies where the rhyolite has intruded the sediments away from the granite contact, especially where the sediments are limestones, and a few deposits are found in the limestone away from the intrusive masses. The deposits along the granite contact and in association with the rhyolite consist largely of magnetite, but those entirely within the limestone, at some distance from the igneous rocks, are composed of dark-brown porous limonite.

The ore associated with the igneous rocks is mainly a glossy, black, compact magnetite with seams and specks of limonite. Locally this ore grades into blue, fine-grained magnetite with chlorite, quartz, and calcite disseminated through it, similar to some of the Taylor Peak ore. In the Iron King cut, masses of serpentine and quartzite are interlayered with the magnetite. Large masses of brown ocherous material, which probably represent partial replacements of the limestone-shale formation, occur between the sediments and the ore bodies. This partly replaced border varies in thickness and degree of alteration; in some places it consists merely of stained quartzite, but elsewhere it is soft and friable and contains numerous veins of magnetite, limonite, chlorite, and kaolin. Here and there masses of partly replaced sandstone and shale occur as lenses surrounded by ore or as bands between adjacent ore deposits. The sediments near the ore deposits are heavily impregnated with contact minerals, among which the most conspicuous are epidote, chlorite, amphibole, pyroxene, garnet, pyrite, and magnetite.

From the foregoing statements it is clear that the iron ores are replacements of the calcareous parts of the limestone-shale formation. The nature of the gangue minerals shows the solutions to have had a deep-seated source, but the distribution of the deposits does not show as clearly as the Taylor Peak deposits the nature of this source. The fact that the deposits lie along the granite contact seems to point to the granite as the source, yet that rock is presumably much older than the overlying rocks that contain the ores. The association of the intrusive rhyolite with the granite contact and hence with the ores appears more significant. It is

[1]Harder, E. C., The Taylor Peak and Whitepine iron-ore deposits, Colorado: Bull. U. S. Geol. Survey No. 380, 1909, pp. 188-198.

probable that the rhyolite intruded at this horizon, because it was easier of access, on account of the fracturing, and that the ore-bearing solutions were associated with it. Direct evidence for this hypothesis is not everywhere plain, yet the ore bodies and the rhyolite are closely associated and the sediments become altered and iron stained as the intrusive rock is approached.

Harder evidently overlooked the intrusive quartz monzonite within a few hundred feet of the magnetite. This oversight could be readily explained by the similarity in appearance of the weathered quartz monzonite and weathered granite. In general, the alteration of the sediments in contact with the porphyry dike is insignificant in comparison with the contact metamorphism brought about by the intrusion of the quartz monzonite batholith. In the opinion of the present writer the magnetite body, in all probability, owes its origin to emanations or solutions from the quartz monzonite intrusion.

FISSURE VEINS

Fissure veins are found in the pre-Cambrian granite, the Princeton quartz monzonite, and the Etna quartz monzonite porphyry. There are now but few opportunities to observe these veins. On a few slopes where talus has not accumulated they may sometimes be found outcropping, and they may be observed in a few prospects. But most of the mines which have opened up these veins are now closed, and nearly all the shallow prospects are caved. However, the proportion of vein material to country rock on many dumps indicates that the veins for the most part vary from a few inches to three or four feet wide. The Spar Copper vein in the Parole tunnel is said to average about three and one-half feet wide. The Lilly vein is reported to be eight inches to five feet wide. The veins vary in strike from due north to N. 65° E. Those that have been observed stand vertical or dip northwestward at a high angle.

By far the greatest number of the fissure veins are in the quartz monzonite; a few are in the quartz monzonite porphyry. The veins in these rocks probably owe their origin to fissures formed by contraction of the crust of the intrusive body, as it cooled and crystallized, and a subsequent filling by mineral solutions from the more highly heated deeper portions of the intrusive bodies. The only fissure veins in the granite that have been observed in this district are within a few hundred feet of the quartz monzonite with which they are probably genetically connected.

The vein filling is commonly quartz with more or less pyrite, but workable ore bodies containing native gold and silver, tetrahedrite, chalcopyrite, galena, and zinc blende have been found. In the few veins that occur in the porphyry, fluorspar, calcite, and quartz are common. Each may occur in masses a foot or more in diameter.

BOG IRON ORE

A small deposit of bog iron ore is exposed in an open cut near Tomichi Creek, about a mile and a half above Whitepine. The deposit is shown by the cut to be at least three feet thick. It is porous and replaces vegetable material. There is much pyrite in the igneous rocks on the slopes east of the creek; and it is from this pyrite, by oxidation and hydration, and from the ferromagnesian minerals of the same rocks, by weathering, that the limonite was probably derived.

OXIDATION AND SECONDARY ENRICHMENT

The available information on these subjects is scant, yet it is evident that nearly all the mines have produced oxidized ore from near the surface. Lead carbonate is said to have been very common and lead sulphate is said to have been mined in quantity on the Eureka claim. Evidently the zone of thorough oxidation did not greatly exceed 100 feet in depth. In the Morning Star mine carbonate ore was mined at a depth of about 100 feet and upward. Sulphide ore was found in the Victor mine 75 feet below the surface. The Mint report for 1883 states that the ore exposed in three shafts 110 to 130 feet deep in the North Star claim, was chiefly galena. But few of the shafts in the sedimentary area are over 200 feet deep, yet sulphide minerals may be found on nearly all the dumps from the deeper shafts. Pyrite has been found in a few prospects in the sedimentary area at a depth of about 20 feet, though oxidation is well advanced. In the area of igneous rocks, much pyrite has been taken from shallow prospects in the fissure veins. Much of the pyrite shows that oxidation is well advanced.

In the Princeton tunnel at a depth of about 100 feet there has been partial removal of the pyrite and deposition of a thin coating of chalcocite on the remainder. This is the only known strong mineralogical evidence of secondary sulphide enrichment in the fissure veins, but it is very probable that part of the high-grade silver ores that have been mined from these veins was in the zone of sulphide enrichment. Evidences of this are the oxidized zone overlying the sulphides and the evident rapid decrease in values of the sulphides with increasing depth[1]. The same evidence holds for probable secondary sulphides in the replacement deposits. No high-grade ore has been reported from the deepest workings of the mines that are now idle. While perhaps incapable of proof, on mineralogical and textural grounds, the rich sulphide ore of the Morning Star mine suggests enrichment by the deposition of secondary sulphides. While the minerals all have a fine grain there are thin veinlets of galena penetrating the ore which is composed chiefly of zinc blende. The galena was evidently deposited later than the zinc blende. It is probable that the zinc blende was deposited from sulphate solutions originating in the oxide zone above which now retains no zinc. The less soluble lead escaped complete removal and much of it remained in the oxidized zone as the carbonate while a small proportion was probably carried below to be deposited as secondary galena. The sulphide minerals from the bottom of the shafts of most of the mines are coarse in texture and display no regularity in arrangement. The slight evidence available, therefore, seems to favor the opinion that the oxidized zone in this district is but little, if any, more than 100 feet deep, and that the zone of sulphide enrichment does not extend more than 300 feet below the surface.

GENESIS OF THE ORES[2]

The structural relationships of the sedimentary and intrusive rocks; the presence of characteristic contact-metamorphic minerals with or near certain ore bodies; the general mineralization of the granite near the quartz monzonite; and the community of ore minerals in the replacements, in fissure veins in the granite, and in fissure veins in the quartz monzonite point to the quartz monzonite intrusion as the source of most of the ore bodies. It is not improbable that the mineral-bearing solutions emanated in large part from the magma.

Possible exceptions, among the replacement deposits, to this origin, are the ore bodies in contact with the rhyolite

[1]See Ransome, F. L., Criteria of downward sulphide enrichment: Economic Geology, vol. 5, 1910, pp. 205-220.

[2]See also "genesis of the ores" of the Monarch district, in Chapter X.

porphyry dike. Yet this dike is narrow, and its margin of pitchstone indicates that it either carried but little mineralizing vapor or cooled rapidly, or both. Under such conditions it seems hardly reasonable to believe that any genetic relationship exists between it and some of the largest known ore bodies in the district. More probably this dike was intruded near and through ore bodies previously formed.

DEPTH AT WHICH THE ORES WERE DEPOSITED

The reasons for believing that the Monarch ores were deposited at a depth of at least 7,000 feet, were stated in the previous chapter. The Tomichi ores were, in all probability, deposited at the same time and at a similar depth. A cover at least 7,000 feet thick has probably been removed by erosion since the ore bodies were formed.

FUTURE OF THE DISTRICT

Though the enterprise of only a few of the mine owners is locally evident, the geology of the district offers much for encouragement. Opportunities for underground study are few, and what follows is based almost exclusively on observations made at the surface. There is no available information concerning the degree of continuity of most of the ore bodies previously mined, but in view of the shallowness of the mine workings it is evident that continuous shoots of large size, of rich ore, were rare or absent. Nevertheless, thick strata of easily replaceable limestone, connected by faults with a large batholith of quartz monzonite of later age or directly crosscut by the quartz monzonite intrusion should provide conditions favorable to the deposition of metallic minerals. Whether or not there has been extensive mineralization or whether possible mineral deposits would take the form of pyrite or more valuable minerals, only deep prospecting can determine. If the abundant limonite at the surface is indicative of payable ore below, as it is in the Monarch district, extensive prospecting is justified. There is perhaps but little to encourage single-handed prospecting or the extensive development of a single claim in the sedimentary area, but the development of claims in groups could be effected economically. The consolidation of interests and a concentrating mill to treat the sulphide ore that evidently exists in the old mines would do much toward placing these properties on a paying basis.

In those fissure veins which contain ore of too low grade for shipping the quantity and availability of the ore for concentrating should be thoroughly investigated. A number of samples were collected from the dumps of shallow prospects in the fissure veins west of Tomichi Creek, in order to determine whether or not they carried gold and silver in appreciable quantity. The samples were collected throughout an area of three or four square miles. All are from shallow prospects, mostly less than 20 feet deep. No samples from former producing mines were assayed, and several specimens of good galena were not tested. The character of the samples and the amount of gold and silver which they contained are shown in the following table:

Assays of samples from prospects in fissure veins

	Ounces gold per ton	Ounces silver per ton
Quartz and galena	trace	25.50
Quartz, galena, sphalerite, pyrite	trace	4.42[1]
Quartz and pyrite	trace	15.75
Quartz and pyrite	none	1.57
Quartz and pyrite	trace	1.40
Compact quartz	.12	4.88
Quartz and pyrite	.14	.86
Iron-stained quartz	trace	1.50
Quartz and galena	.02	none
Quartz and galena	.08	19.47
Quartz and pyrite	trace	2.35
Quartz	.24	7.84
Quartz	3.58[2]	267.70[2]

The amount and availability for concentration of the copper ore on the northwest slope of Copper Hill should receive attention.

At the risk of error, a few virtually unprospected localities and horizons that seem to merit examination, will be mentioned. In several of these localities the presence or absence of ore bodies could probably be ascertained at little expense. Faults in the limestone, wherever they are not too far from the quartz monzonite, should be prospected. Locally, these show much limonite at the surface. The rock along the Morning Glim fault is mineralized as far southeast as the Annie Hudson mine. Whether or not this fault intersects the Star fault is uncertain. Though pronounced displacement in line with the Star fault,

[1]Average of two assays.
[2]Average of three assays.

near the Morning Glim fault, where Galena Creek crosses the latter, may not have taken place, the rock is probably much fractured and should be susceptible of replacement. This could be tested, at small cost, by sinking a shaft through the alluvium. The faults near the quartz monzonite west of the northwest corner of the area mapped, might carry ore bodies. The geology in this part of the district is similar to that of Lake Hill.

The limestone immediately overlying the granite has been prospected only superficially. Evidences of ore bodies here are found in the sulphide ores of the West Point mine, in the deposits of psilomelane on the west slope of Lake Hill, and in the record of the Little May and May Mazeppa mines which are in this limestone. It is hardly probable that all the replacement deposits near the quartzite strata have been discovered. Limestone in contact with the quartz monzonite should receive attention.

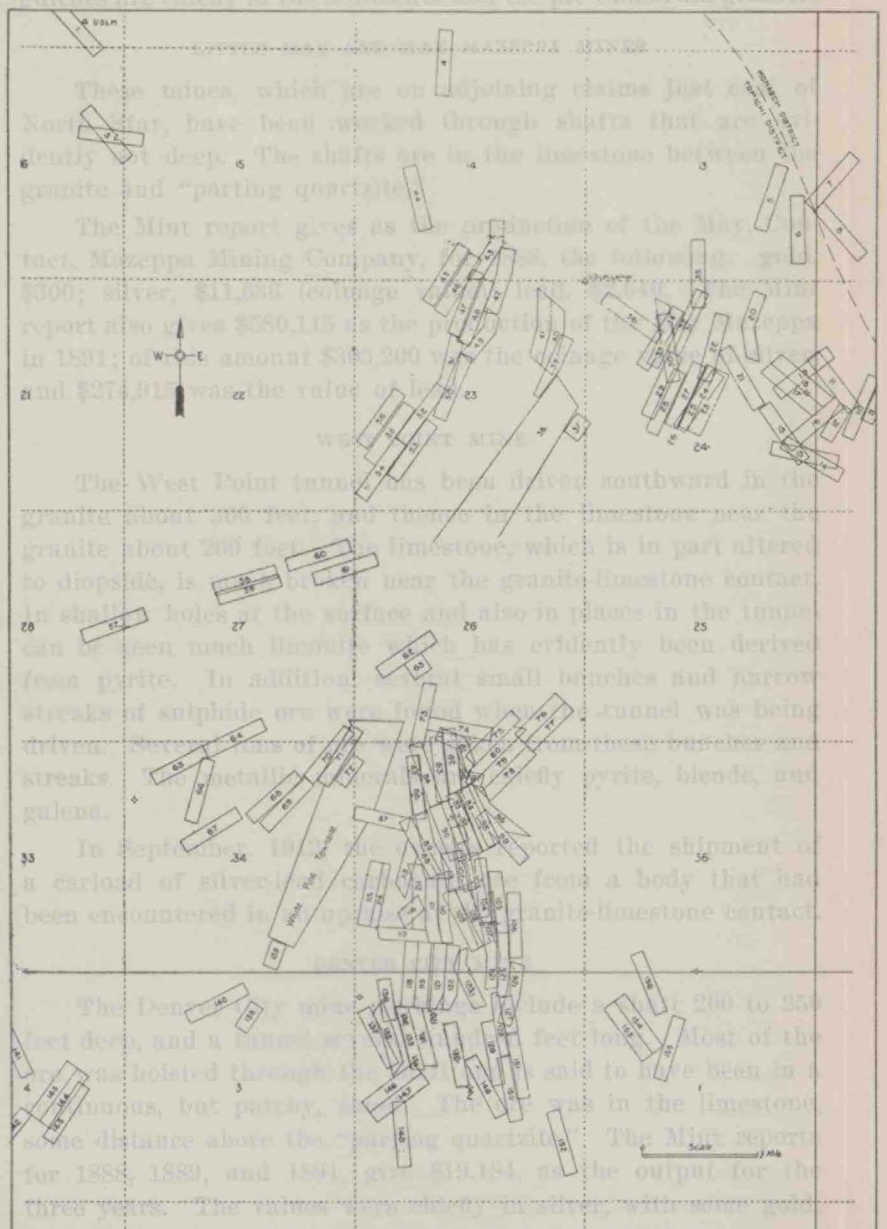
The sedimentary area should be reprospected for zinc. In the eighties this metal was avoided and payable ore bodies may remain in the old mines. Specimens of good zinc ore were collected from the Denver City, Breadwinner, and Annie Hudson dumps in the course of the field work. The quantity of this ore in the mines is unknown.

DESCRIPTIONS OF MINES

Since for many years most of the mines have been idle they are now caved or partly filled with water. But few could be entered when the Survey party was in the field. Such observations as could be made are recorded in the following pages, and to these observations have been added notes from other sources concerning a few mines. The output, when given, of mines for single years or a few years, taken from the Mint reports, in all probability is not the total output of most of the mines so reported. The output of the same mines for other years, was probably included with the confidential reports.

The mines, in so far as it can be done conveniently, will be described in a geographical order, beginning with those southeast of Whitepine. In large measure this is also a geological grouping, since the ores of the mines east and southeast of Whitepine are chiefly replacements in Paleozoic sediments; the ores west of Tomichi Creek are chiefly in fissure veins in

Colorado Geological Survey — Bulletin 4, Plate XXV



MAP OF MINING CLAIMS OF THE TOMICHI DISTRICT

Compiled from plats in the Surveyor General's office.

INDEX TO CLAIMS

Index Number	Patent Number		Index Number	Patent Number	
1	5083	Blue Bell	81	4808	Iron King
2	1481	Anna	82	1062	Iron Duke
3	1483	Lippincott	83	1061	Parole
4	1482	Clinton	84	2494	Bob Lee
5	2094	Fort Scott	85	2500	Early Bird
6	2210	Oddie	86	1885AM	Garfield
7	3795	Moose	87	1906	Hutchinson
8	4300	D. A. Mason	88	2615	Dusky Bell
9	3144	Star of the West			(2 lodes)
10	3143	Grey Elephant	89	2615	Excelsior
11	3147	Red Cloud	90	17383	Comstock, Jr.
12	3142	Pocahontas			(2 lodes)
13	984	Philadelphia	91	17383	Belvidere
14	987	Freeport	92	18876	Hartford
15	985	Rockford	93	1987	Pueblo
16	986	Miners Relief	94	1986	Mary Campbell
17	7156	Josephine	95	1985	Sam T.
18	7156	Alert	96	4508	Ensign
19	2194	Limestone	97	4539	Morning Glim
20	2114	John Mouat	98	8312	Vulcan
21	991	Livingstone	99	8312	Iron Mask
22	1150	Little Ernest			(2 lodes)
23	17589A	Prescott	100	1982	Silver Trowel
24	1784	Robt. E. Lee	101	18861	Paymaster
25	17589A	Modoc	102	18861	Nimrod
26	17589A	Modoc No. 2	103	1981	Sunset
27	1134	Bill Short	104	2070	Erie
28	1905	Lavina	105	2511	Lelia Etta
29	2495	Caribou	106	2512	Sedalia
30	1729	Black Carbonate	107	1942	Silver Bayonet
31	992	J. B. Fricky	108	18026	Monitor
32	1937	Cinnamon	109	1871	Bandit
33	1934	E. Ford	110	18965	Yellow Jacket
34	1936	M. L. Ayers	111	2498	Mazeppa
35	2120	Lone Star	112	2333	Little May
36	1935	Henry Lawrence	113	4540	Isabel
37	175898	Clover Mountain	114	15544	Caladonia
		M. S.	115	15544	Mayflower
38	406	Raymond Placer	116	847B	M. S.
39	1631	Lehie	117	2332	Lost Contact
40	2240	Lizzie Brant	118	850	No. 3
41	2239	Little Carrie	119	849	Muldoon
42	870	Uncle Sam	120	848	Narrow Gauge
43	585	San Juan	121	847A	North Star
44	7874	Little Maud			(lode and M.S.)
45	2116	Silver Gem	122	1872	Deadwood
46	2117	Eastman	123	1606	Haverford
47	2118	Topeka	124	1555	Nest Egg
48	2119	Little Minnie	125	1574Am	Eureka
49	2115	Gray Copper	126	7956	Lehigh
50	2142	Mammoth	127	15553	Little Alice
51	2143	Sleeping Pet	128	6692	Little Giant
52	1060	Lewiston	129	1941	David H.
53	2658	Little Boss	130	1966	John G.
54	2657	Morning Star	131	6575	Morning Star
55	3656	Lamar	132	12462	Victor
56	2670	Junction	133	5891	Beta
57	2257	Hawkeye	134	17173	Victor
58	1605	Black Hawk	135	13295	Mattie E. (2 lodes)
59	1604	Princeton	136	13295	W. A.
60	4705	Deertrail	137	1940	Denver City
61	4704	Hurricane	138	11525	The Tomichi M. S.
62	2030A	Ella May	139	2073B	M. S.
63	2030B	M. S.	140	2170	Potosi
64	1969	Minnie M.	141	2674	Healsburg
65	2073A	Flirt	142	17748	Liberty Belle
66	1865	Phoenix	143	17748	Snow Bird (2 lodes)
67	7273	Bonita	144	6938	Sulphuret
68	1417	Romance	145	6938	Chicago
69	1873	Alwilda	146	19137	Inspiration
70	1874	Bullion			(2 lodes)
71	1521A	Coin Silver	147	19137	Last Chance
72	1521B	M. S.	148	6530	Tyrone
73	2305	Jersey	149	17384	Gopher
74	2415	Snowdon	150	15554	Black Diamond
75	18544	Spar No. 4	151	1967	Little Iron
76	18544	Greenbrier No. 1	152	6777	Mogul
77	18544	Greenbrier No. 2	153	5872	Wolverine
78	18544	Spar No. 3	154	5872	Leonora
79	18544	Spar (2 lodes)	155	2187	Nancy
80	18544	Spar No. 2	156	1695	Anna Hudson

the quartz monzonite; while those of Robbins and Fort Scott gulches are chiefly in the sediments and the pre-Cambrian granite.

LITTLE MAY AND MAY MAZEPPA MINES

These mines, which are on adjoining claims just east of North Star, have been worked through shafts that are evidently not deep. The shafts are in the limestone between the granite and "parting quartzite."

The Mint report gives as the production of the May, Contact, Mazeppa Mining Company, for 1888, the following: gold, $300; silver, $11,636 (coinage value); lead, $2,640. The Mint report also gives $580,115 as the production of the May Mazeppa in 1891; of this amount $305,200 was the coinage value of silver, and $274,915 was the value of lead.

WEST POINT MINE

The West Point tunnel has been driven southward in the granite about 300 feet, and thence in the limestone near the granite about 200 feet. The limestone, which is in part altered to diopside, is much broken near the granite-limestone contact. In shallow holes at the surface and also in places in the tunnel can be seen much limonite which has evidently been derived from pyrite. In addition, several small bunches and narrow streaks of sulphide ore were found when the tunnel was being driven. Several tons of ore were taken from these bunches and streaks. The metallic minerals are chiefly pyrite, blende, and galena.

In September, 1912, the owners reported the shipment of a carload of silver-lead carbonate ore from a body that had been encountered in an upraise at the granite-limestone contact.

DENVER CITY MINE

The Denver City mine workings include a shaft 200 to 250 feet deep, and a tunnel several hundred feet long. Most of the ore was hoisted through the shaft and is said to have been in a continuous, but patchy, shoot. The ore was in the limestone, some distance above the "parting quartzite." The Mint reports for 1888, 1889, and 1891, give $19,184, as the output for the three years. The values were chiefly in silver, with some gold, lead, and copper. The tunnel is reported not to have opened up much ore, but specimens of good calamine and malachite may be found in the ore bin at the tunnel.

VICTOR MINE

The Victor mine—formerly called Beta mine—has been worked through an inclined shaft and a short tunnel. (See Pl. XVI, *B*.) Most of the ore was produced in the nineties and was hoisted through the shaft. The ore bodies were inaccessible in 1910 and 1911, but Mr. Emil Peterson, one of the owners, has furnished the information given in the next paragraph.

The largest ore body hitherto discovered in the mine extended from the surface to a depth of 182 feet and was just west of the porphyry dike that may be seen in the Morning Star mine. The longest drift on the ore has a length of 300 feet. The greatest thickness of the ore body was eight feet. The ore was chiefly silver-bearing lead carbonate and averaged $62.00 a ton in value. A few years ago a tunnel, which was driven 200 or 300 feet, cut a body of sulphide ore about 75 feet below the surface on the east side of the porphyry dike—that is, between the porphyry and granite. This ore was in or near the Star fault. Of the four carloads shipped from the tunnel the best ran 93 ounces silver per ton, 26 per cent lead, and 6 per cent copper. A winze was sunk 50 feet from the tunnel, but work was suspended on account of the large volume of water. The production of the mine has been about $500,000.

Specimens from the dump of the old workings show a little galena, calamine, azurite, and malachite. The dump shows much iron stain. Specimens from the tunnel carry galena with tennantite and a little pyrite. The ore is penetrated by narrow veins of calcite.

The mine is equipped with a steam hoist.

MORNING STAR MINE

The Morning Star mine is worked through an inclined shaft 240 feet deep—on the pitch—and a tunnel about 600 feet long. The tunnel intersects the shaft about half-way between the collar and the sump.

The ore of this mine lies partly in the Star fault, between limestone and granite, but chiefly in the limestone just west of the fault. The ore is partly above and partly below the eastward-dipping rhyolite porphyry dike which cuts the limestone a few feet west of the fault. The contact between the ore and limestone is generally sharp, but evidence that the ore is a replacement deposit is found in the residual blocks of limestone, several inches in diameter, surrounded by ore, about 40 feet above the bottom of the shaft. Although all the ore seen by the writer was sulphide ore, lead carbonate is reported to have extended down about 100 feet from the surface.

On the tunnel level a drift just east of the porphyry dike extends north 220 feet from the tunnel. It is reported that more or less ore was found throughout this distance. A small quantity of low-grade ore was showing in the face of the drift when the mine was visited. Oxidized ore, one to five feet thick, is reported to have extended upward 50 feet from the tunnel level where an upraise, near the tunnel, was driven.

Just north of the bottom of the shaft a sulphide ore body about 15 feet wide was found. The ore extended north 25 feet where it narrowed to about one foot. This ore was in broken limestone a few feet west of the porphyry dike. About 40 feet higher, on the north side of the shaft, a face of ore six feet wide was seen. Apparently the shaft was sunk most of the distance in ore.

In 1911 an upraise, starting east of the bottom of the shaft, had been driven in sulphide ore nearly 100 feet when the mine was visited. Both sides of the upraise, which was 6 by 6 feet in cross-section, were of ore. The upraise was inclined 47° from the horizontal—that is, the ore dipped eastward 47°. This ore, whose determinable minerals were blende and galena, was in the limestone above the porphyry and evidently not many feet from the granite.

On August 1, 1911, the bins contained about 300 tons of ore which could not be hauled to the railroad, at that time, on account of the bad condition of the road, caused by excessive rains. It is reported that later in the year about 75 carloads of ore were shipped. No definite information of the value of this ore in carload lots has been obtained. A supposedly average sample, from near the bottom of the shaft, assayed by Mr. Watts, ran .14 ounces gold and 19.10 ounces silver per ton, 22.7 per cent lead, and 45.0 per cent zinc. This sample was composed of blende and galena with a few small crystals of pyrite.

A crosscut, on the tunnel level, has been driven several hundred feet eastward in the granite. It is proposed to continue this crosscut to the granite-limestone contact, which has not yet been prospected more than a few feet below the surface. Farther down on the hillside a tunnel was being driven in 1912; in

July it had reached a length of 300 feet. This tunnel is expected to cut the Morning Star ore shoot 175 feet vertically below the bottom of the shaft.

The mine is equipped with a gasoline hoist and fan.

NORTH STAR MINE

This mine, which was operated only a few years, was worked through several shafts of which the deepest is 365 feet in depth. The ore was in or near the Star fault. Much limonite was found near the surface, and although part of the ore was oxidized, it is said that most of the ore produced was silver-bearing galena. A little pyrite and galena may be seen on one of the dumps.

The Mint report for 1884 states that a large force had been employed throughout the year and that the output was four to six carloads of ore per week.

The Dividend shaft—the deepest one—is covered by a good shaft house and equipped with a steam hoist.

BREADWINNER MINE

This mine, which has produced only a small quantity of ore, was worked through a shallow shaft in the limestone not far above the "parting quartzite." A few hundred pounds of zinc ore—chiefly calamine—lay on the dump in 1910. A sample assayed by Mr. Watts, carried 37.70 per cent zinc.

DAVID H. MINE

The David H. mine has been worked through shallow shafts just above the black dolomite of the Ouray formation. The dolomite has been changed to tremolitic marble; at about 400 feet north of the main shaft the marble carries a small quantity of galena. The ore of the mine is said to have been pockety and all that was mined came from within 100 feet of the surface. Galena was the most important ore mineral, but cerussite, tetrahedrite, and stephanite were also present. Specimens of cerussite and calamine may be seen on the dumps; a specimen of good stephanite from this mine was kindly furnished by Mr. W. T. McConnell.

The mine is equipped with a steam hoist.

EUREKA AND EUREKA-NEST EGG MINES

These mines were worked through a number of shafts near the upper part of the Ouray limestone. The surface ore is said to have been principally silver-bearing lead carbonate with some lead sulphate. The ore of the deeper workings was chiefly silver-bearing galena.

The Mint reports give $92,904 as the production of these mines for the years 1887, 1888, and 1891.

ERIE MINE

The Erie mine is worked through a shaft at about the same stratigraphic horizon as the Eureka mine. A large body of low-grade zinc ore is said to be opened up. In 1910 the bin contained several tons of ore composed of zinc blende, pyrite, galena, and a little chalcopyrite. The ore would probably concentrate well; with the present price of zinc it should be payable shipping ore. Some ore has been shipped from a winze sunk from a short tunnel on the Erie property, a few hundred feet north of the main shaft. In 1910 about a carload of ore was on the dump at the tunnel. This ore was similar to that in the bin at the shaft but carried a larger proportion of zinc blende.

The output of the Erie is not known to the writer, but the Mint report for 1891 gives $16,399 as the production for that year. Of this amount $11,745 was the value of lead and $4,654 the coinage value of silver produced. It is reported that work in this mine was resumed in the autumn of 1912.

The Erie shaft is equipped with a steam hoist.

ANNIE HUDSON MINE

Several caved tunnels and shafts may be seen on the Annie Hudson property, in and near the Morning Glim fault where it crosses Galena Creek. Much limonite is found at the surface and on the dump. The property has evidently not produced much ore, but about two tons could be seen near one of the tunnels in 1910. The ore was chiefly zinc carbonate with a little galena. An average specimen assayed by Mr. Watts yielded 41.00 per cent zinc. The same sample carried 5.25 ounces silver per ton.

SPAR COPPER MINE

The Spar Copper mine includes the Morning Glim and the Parole tunnels. The Morning Glim tunnel starts in the Paleozoic sediments, a few feet south of the Morning Glim fault and extends northeast about 1,200 feet. Through most of its course the tunnel is said to follow a vein in the granite. The Parole tunnel starts about 800 feet west-northwest of the portal of the Morning Glim and about 200 feet lower. It crosscuts the sediments to the fault whence a drift has been run northeast about 500 feet along a fissure vein in the granite. This vein is evidently the same as that opened by the Morning Glim tunnel and dips a few degrees from vertical toward the northwest. The vein on the lower level is not wide but carries good ore through a considerable part of its course. When seen by the writer, in 1910, the vein had been opened only a short distance and was nearly barren in the breast of the drift. However, a streak of good ore about a foot wide was showing in the top of the drift not far from the breast. Several carloads have been shipped from this level within the past two years.

The ore of the Morning Glim tunnel is reported by the old miners of the district to have carried very high values in silver. It is stated that native copper, lying directly on the granite, was also found in this tunnel. Specimens in the Morning Glim ore bin are chiefly galena with copper-bearing pyrite and vein quartz. One specimen collected, shows enargite associated with pyrite.

Manager T. H. Jenks has kindly furnished the following notes on the vein and ore as seen in the Parole tunnel: The vein averages about three and one-half feet wide and the pay-streak about one foot. The latter varies considerably as to position in the vein, being found both on hanging and foot wall, and sometimes broken up into two or three stringers which invariably come together within a short distance. Both vein and pay-streak are continuous for a distance of about 500 feet though the latter pinches somewhat for about 100 feet of this distance. The vein occasionally opens into wider masses or lenses of ore, but invariably seems to hold its value. The ore consists of galena and chalcopyrite, together with tetrahedrite and pyrite, and generally carries a slight excess of silica with some calcite. There is also some sphalerite, though not enough to cause a penalty at the smelter. The principal value is silver, generally associated with galena and gray copper. Gold is also present in paying quantity.

There are two other known veins on this property. One, locally known as the "Sitting Bull" is a silver ore carrying no lead or copper. Samples taken from this vein show 40 to 112 ounces silver per ton with appreciable gold values.

The production of the mine is not definitely known, but according to the most reliable information that Mr. Jenks has, it is not less than $40,000.

IRON KING MINE

This mine is at or very near the Morning Glim fault in a deposit of magnetite. Several carloads of ore have been shipped, but the operation of the mine proved unprofitable on account of the long haul and consequent heavy freight charges. In 1910 the mine showed a face of magnetite, about 30 feet high. The magnetite is associated with serpentine and tremolite, and in places, carries a copper stain. It is reported that two tons of rich copper ore, in the form of cuprite, were shipped from the surface near the magnetite body, but no other payable copper ore has been found in this vicinity.

LILLY MINE

The Lilly mine is in a northward-striking fissure vein in the Princeton quartz monzonite, near the contact between this rock and the pre-Cambrian granite. The dump is composed mainly of vein quartz with some pyrite. Mr. Dick Teller, one of the owners, has kindly furnished the information which follows:

The Lilly shaft is 200 feet deep. At 150 feet, a drift was run north 300 feet, and south 150 feet. At 200 feet a drift extends 40 feet north, and 120 feet south. The vein varies from eight inches to five feet in width. On the 150-foot level the ore extends nearly the length of the drift toward the north; the south drift is chiefly in pyrite, though the vein did not pinch. On the 200-foot level there was much barite and a small quantity of ore minerals in the north drift, but no shipping ore was found here. On the same level, some ore was taken from the south drift. The ore was all gray copper which ran up to 200 ounces in silver per ton. Very little gold and lead were present. The total production has been about $40,000.

The mine is equipped with a steam hoist.

SILVER CORD MINE AND ALWILDA TUNNEL

The Silver Cord mine is also in a fissure vein in the quartz monzonite. The dump is vein quartz with pyrite and a little galena. In 1910 one or two tons of ore—galena and a little pyrite associated with quartz—lay on the platform near the shaft. According to Mr. Teller, this mine has produced one carload of ore which ran 85 ounces silver per ton and 40 per cent lead. The shaft is 140 feet deep.

The Alwilda tunnel is being driven to cut the Silver Cord and Lilly veins at a depth of 500 to 700 feet. This tunnel is now in nearly 1,000 feet.

LEWISTON AND PET MINES

These mines were worked many years ago through shafts which evidently are not deep. The dumps are chiefly of quartz monzonite with some vein quartz and considerable porphyry. It is stated that very high grade ore was shipped from the mines in the eighties and that the ore contained about 20 ounces silver for each ounce of gold. Both metals are said to have been present in the free state. The Mint report gives $2,000 and $500 as the value of gold and silver, respectively, for the year 1887.

HIAWATHA MINE

The Hiawatha shaft is perhaps 100 feet deep. The dump is largely quartz monzonite, but it is reported that some ore was found in a vein opened by the shaft.

FORT SCOTT MINE

This mine, near the head of Fort Scott Gulch, is at or near the contact between Paleozoic sediments and volcanic breccia, and not far from the Etna porphyry. It is said to have produced 10 or 12 carloads of ore whose chief values were in gold and silver.

LEGAL TENDER MINE

This mine, which is near the head of Robbins Creek, has not been operated for many years. The several dumps show pre-Cambrian granite, Paleozoic sediments, quartz monzonite gneiss, Etna porphyry, and volcanic breccia. Apparently the ores were chiefly in the sedimentary rocks. Limonite is abundant on the dumps. Several tons of pyrite with fine-grained blende could be seen in 1910. A small quantity of smithsonite was present.

Near the top of Clover Mountain and perhaps on the Legal Tender property, about a ton of oxidized ore has been sacked at a shaft sunk at the contact between the Etna porphyry and sedimentary rocks. Much of the ore is anglesite of good grade.

DEFIANCE MINE

The Defiance mine on Robbins Creek, has been worked through a shaft and short tunnel in the pre-Cambrian granite, a few hundred feet from a quartz monzonite stock. A small quantity of good zinc blende, with vein quartz, may be seen on the dumps. It is said that several carloads of ore were shipped from this mine in the early eighties.

BILL SHORT MINE

This mine is in Robbins Gulch, near the contact between the pre-Cambrian granite and the quartz monzonite. Much of the dump is quartz monzonite. Specimens of ore on the dump are composed chiefly of galena and blende, in quartz. Some of the blende has a yellow coating of greenockite. The mine is reported to have produced ore in recent years.

A few hundred feet east of the portal of the Bill Short tunnel, a tunnel in the pre-Cambrian granite has opened a narrow vein from which specimens show quartz, much blende, a little galena, a little chalcopyrite and a little greenockite. About two tons of this ore could be seen at the tunnel in 1910.

PROSPECTS

Akron tunnel.—The Akron tunnel, driven eastward from Tomichi Creek, is said to be 3,800 feet long. At the face it should be, therefore, 600 to 900 feet from the surface and not far from the North Star lead. Some mill ore is reported to have been taken from this tunnel.

Isabel.—On the Isabel claim a tunnel opened a small body of ore above the "parting quartzite." The rock is greatly broken by local faulting. The ore is chiefly lead carbonate with a small amount of galena.

Congress tunnel.—The Congress tunnel has been driven into Porcupine Ridge from Galena Creek. In 1910 the ore bins contained some pyrite, but the mine has evidently produced little, if any, ore. The tunnel is equipped with an air compressor housed in a good building.

Chicago tunnel.—This tunnel, on Tomichi Creek, about a quarter of a mile south of the south boundary of the quartz monzonite, has been driven westward in the granite. It is said that nine tons of good lead ore were shipped from the tunnel. Much pyrite may be seen on the dump.

Potosi.—This claim, which is southwest of Whitepine, is said to have produced six tons of silver-lead ore. The shipment returned $28.00 per ton net.

Ben Bolt, Alice, and Princeton.—The Ben Bolt shaft was sunk on a fissure vein in the quartz monzonite. Considerable pyrite and quartz may be seen on the dump, but no shipments have been reported.

The Alice tunnel cuts the Ben Bolt vein which, in the tunnel, strikes about N. 65° E. and dips 75° N. 25° W. In 1910 the vein had been opened by a drift about 30 feet long. At the southwest end of the drift were two veins of ore separated by three feet of quartz monzonite. The veins were six inches and eight inches wide, respectively. At the northeast end of the drift the vein was at least 18 inches wide. The ore, which is galena, blende, and chalcopyrite, with quartz and pyrite, would probably concentrate well.

In 1911, the Princeton tunnel had been driven on the Ben Bolt vein about 400 feet. At the breast the vein was about a foot wide. The hanging-wall rock was much kaolinized. The vein filling is chiefly pyrite and quartz with a little galena. Locally, a thin sooty coating of chalcocite has been deposited on the pyrite.

Magna Charta tunnel.—The Magna Charta tunnel was driven northwest about 4,000 feet in the quartz monzonite. It is under the ridge that extends southeast from Granite Mountain, and was driven to open at depth the north-south veins that were prospected on both sides of the ridge. Several veins are said to have been cut by the tunnel, but no shipping ore was found.

Mann tunnel.—This tunnel, about three-fourths of a mile south of Tomichi Pass, is being driven northwestward in the quartz monzonite to cut a vein that outcrops 100 feet higher. The vein, which is about two and one-half feet wide, can be traced about 60 feet. The vein-filling is chiefly quartz and is said to have assayed $5.85 to $27.00 per ton in gold, silver, and copper.

Tokio.—The Tokio vein, which is in the quartz monzonite, is about a mile east of the top of Granite Mountain. Where it is exposed in a shaft about 30 feet deep, the lead is four feet wide and dips 65° N. 60° W. About three feet of the lead is composed of quartz with a small amount of rock. A specimen from the dump, assayed by Mr. Watts, carried .24 ounces gold and 7.80 ounces silver per ton. Three other samples from the same vein several hundred feet toward the northeast, assayed by Mr. Watts, carried respectively .64 ounces gold and 54.70 ounces silver, 3.32 ounces gold and 163.70 ounces silver, 6.80 ounces gold and 584.70

ounces silver per ton. These samples, which were taken from dumps, were chiefly quartz and showed no metallic mineral in the hand specimens.

Prospects on Canyon Creek.—Much prospecting has been done in the quartz monzonite about half a mile northwest of Mount Stella. At several dumps vein quartz with galena may be seen. About half a mile farther south is a group of prospects in the quartz monzonite and pre-Cambrian granite. At one shaft in the granite and at one shaft in the quartz monzonite considerable good galena with vein quartz was seen. The veins themselves were covered, but the specimens indicate that they are not over a few inches wide.

Prospects of Copper Hill.—Much of the rock at the top of Copper Hill and in the steep ravine on the northeast slope of the same hill shows a green copper stain. In several places the rock—granite and quartz monzonite—is impregnated with enough malachite to form several per cent of the whole. One prospect has opened a narrow quartz vein that carries considerable pyrite, while malachite impregnates the wall rock. Many specimens on the dumps of short tunnels contain veinlets of good malachite. The veinlets have a maximum thickness of one-fourth of an inch.

Prospects in iron ore.—Several short tunnels have been driven across the magnetite-limonite deposits southeast of the Iron King mine. A considerable body of limonite with a small quantity of magnetite is found about one-fourth of a mile northeast of the Annie Hudson mine, in or near the Morning Glim fault.

One-fourth to one-half mile southeast of Lake Hill several shallow shafts have been sunk in limonite and limestone. At one dump is about one carload of ore; there are no indications that the shaft reached the rock below the ore. Evidence that this limonite has been derived from the oxidation and hydration of pyrite is found in the pyritiferous limestone that is found with the limonite on at least one dump. Furthermore, at the same stratigraphic horizon on the northwest slope of Lake Hill is found limonite that is clearly derived from pyrite. Limonite pseudomorphs after pyrite cubes one-fourth inch to two inches in diameter, may be seen. Some of the cubes retain a core of unaltered pyrite.

Placer prospects.—Near the southwest corner of the area mapped some ground was washed for placer gold many years ago. No information concerning the result of this enterprise is at hand.

BUILDING AND ORNAMENTAL STONE

Much of the marble of the Tomichi district is apparently suitable for building purposes. The Princeton quartz monzonite has the same general character in the Monarch, Chalk Creek, and Tomichi districts. The quartz diorite on the west slope of Mount Stella should be suitable for monumental purposes as well as for building. But without a railroad in the district, none of these varieties can compete with the better known stone of more favorably situated localities of Colorado.

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Topography by P. G. Worcester, R. C. Coffin, R. M. Butters, and G. B. Warner.
Surveyed in 1909-10.

TOPOGRAPHIC MAP OF THE MONARCH AND TOMICHI MINING DISTRICTS, COLORADO

Scale 1/62500 or approximately 1 inch to 1 mile

1 ½ 0 1 2 Miles

1 ½ 0 1 2 3 Kilometers

Contour interval 100 feet
Datum is mean sea level

A. HOEN & CO. BALTIMORE.

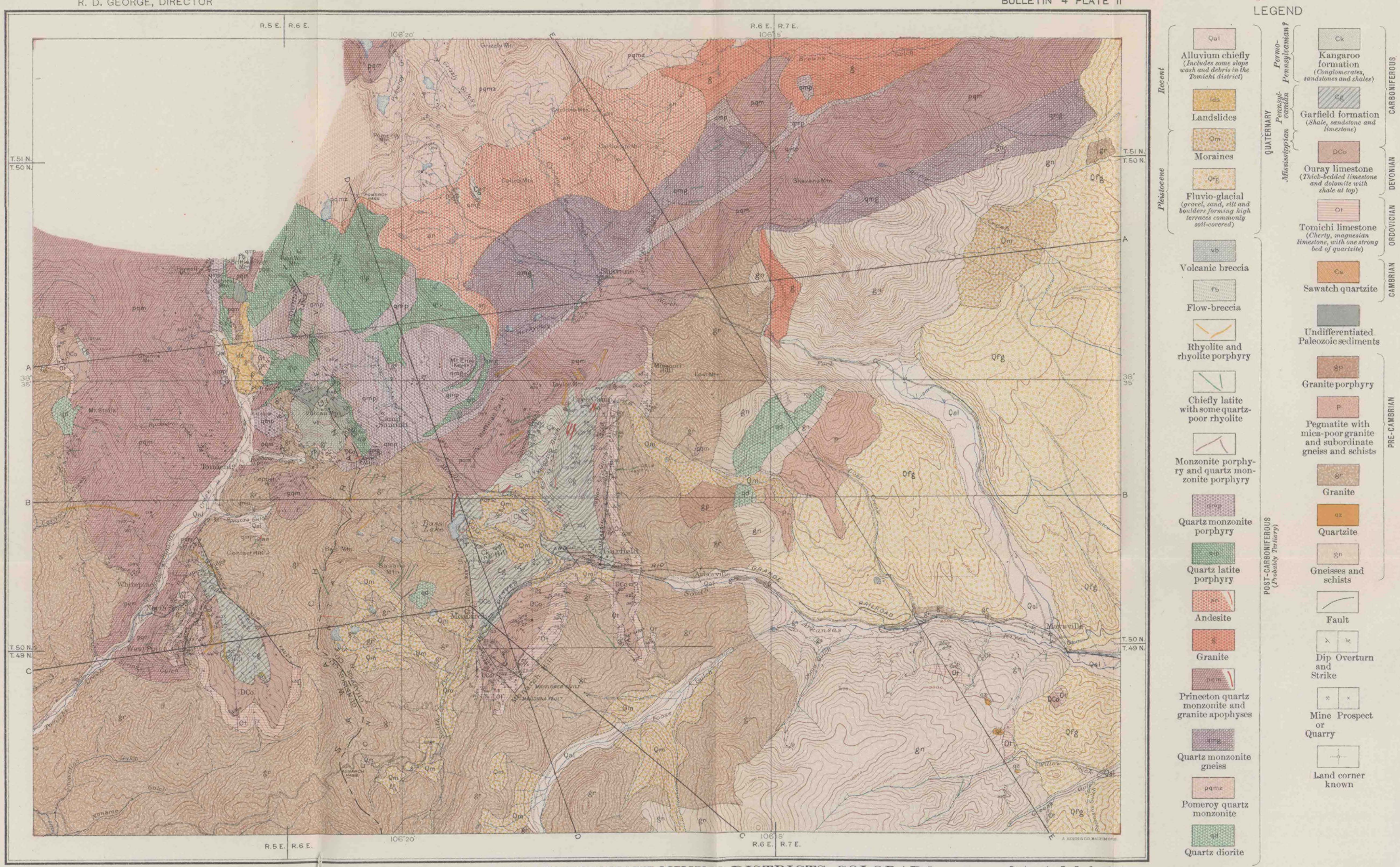
LEGEND

Mine or Quarry — Prospect

Land corner known

MINES, QUARRIES AND PROSPECTS

1 Silent Friend No. 1
2 Silent Friend No. 2
3 Silent Friend No. 3
4 Silent Friend No. 4
5 Hawkeye
6 Hawkeye No. 3
7 Madonna No. 6
8 Madonna No. 5
9 Madonna No. 4
10 Madonna No. 3
11 Madonna No. 2
12 Madonna No. 1
13 Madonna No. 0
14 Wilson lower tunnel
15 Wilson upper tunnel
16 Eclipse discovery shaft
17 Eclipse No. 1
18 Eclipse No. 2
19 Eclipse No. 3
20 Eclipse No. 4
21 Little Wonder
22 Oshkosh
23 Fairplay
24 Monarch Contact tunnel
25 Great Monarch tunnel
26 Great Monarch tunnel
27 Great Monarch shaft
28 Elkington
29 Little Charm
30 Paymaster
31 April Fool
32 Delaware
33 Evening Star incline
34 Evening Star tunnel
35 Black Tiger
36 Marshall tunnel
37 Ingersoll
38 Thirty-six-thirty
39 Ohio and Colorado S. & R. Co. quarry
40 Garfield quarry
41 Garfield tunnel
42 Garfield mine
43 Alaska
44 Exchequer
45 Marble quarry
46 Shamrock
47 Major
48 Missouri Boy
49 Page tunnel
50 Lilly tunnel
51 Lilly shaft
52 Jewell tunnel
53 Denver
54 Lilly
55 Lilly
56 Rainbow-Eagle Bird
57 Rainbow-Eagle Bird
58 Mountain Chief tunnel
59 Mountain Chief shaft
60 Piñon
61 Clinton
62 Clinton
63 Song Bird
64 Indianapolis
65 Stemwinder
66 Last Chance
67 New York
68 New York No. 2
69 Bonnie Bell
70 Ben Hill
71 Fraction
72 Desdemona
73 Beta
74 Alpha
75 Maverick tunnel
76 Golden Age
77 Columbus
78 Columbus
79 Columbus
80 Columbus
81 Brighton
82 Bowman tunnel
83 Darling
84 Hercules tunnel
85 Uncle Sam
86 Tweed tunnel
87 Macedonian tunnel
88 Mohammed tunnel
89 Gulch No. 1
90 Gulch No. 2
91 Gulch No. 3
92 Emma Stradley
93 Mason
94 Moose
95 D'Byron
96 Highland
97 Paymaster
98 Paymaster
99 Bon Ton
100 Stones Junction
101 Lost Basin
102 Condor shaft
103 Condor tunnel
104 Tom Cat
105 North Pole
106 Tom Payne
107 Uncle Sam
108 Orphan Annie
109 May Queen
110 Pride of the West
111 Michigan
112 Hiawatha
113 Fort Scott
114 Lewiston-Pet
115 Magna Charta
116 Bill Short
117 Legal Tender
118 Defiance
119 Princeton tunnel
120 Alice
121 Ben Bolt
122 Iron King
123 Parole tunnel (Spar Copper)
124 Morning Glim (Spar Copper)
125 Alwilda
126 Silver Cord
127 Lilly
128 Isabel
129 Erie
130 Akron tunnel
131 Little May
132 North Star (Dividend shaft)
133 North Star shaft
134 Eureka-Nest Egg
135 Eureka-Nest Egg No. 3
136 Eureka-Nest Egg No. 7
137 Annie Hudson
138 West Point
139 Morning Star tunnel
140 Morning Star shaft
141 Denver City tunnel
142 Denver City shaft
143 Victor shaft
144 Victor tunnel
145 Breadwinner
146 David H
147 Chicago tunnel
148 Congress tunnel



GEOLOGIC MAP OF THE MONARCH AND TOMICHI MINING DISTRICTS, COLORADO

Topography by P. G. Worcester, R. C. Coffin, R. M. Butters, and G. B. Warner. Surveyed in 1909-10.

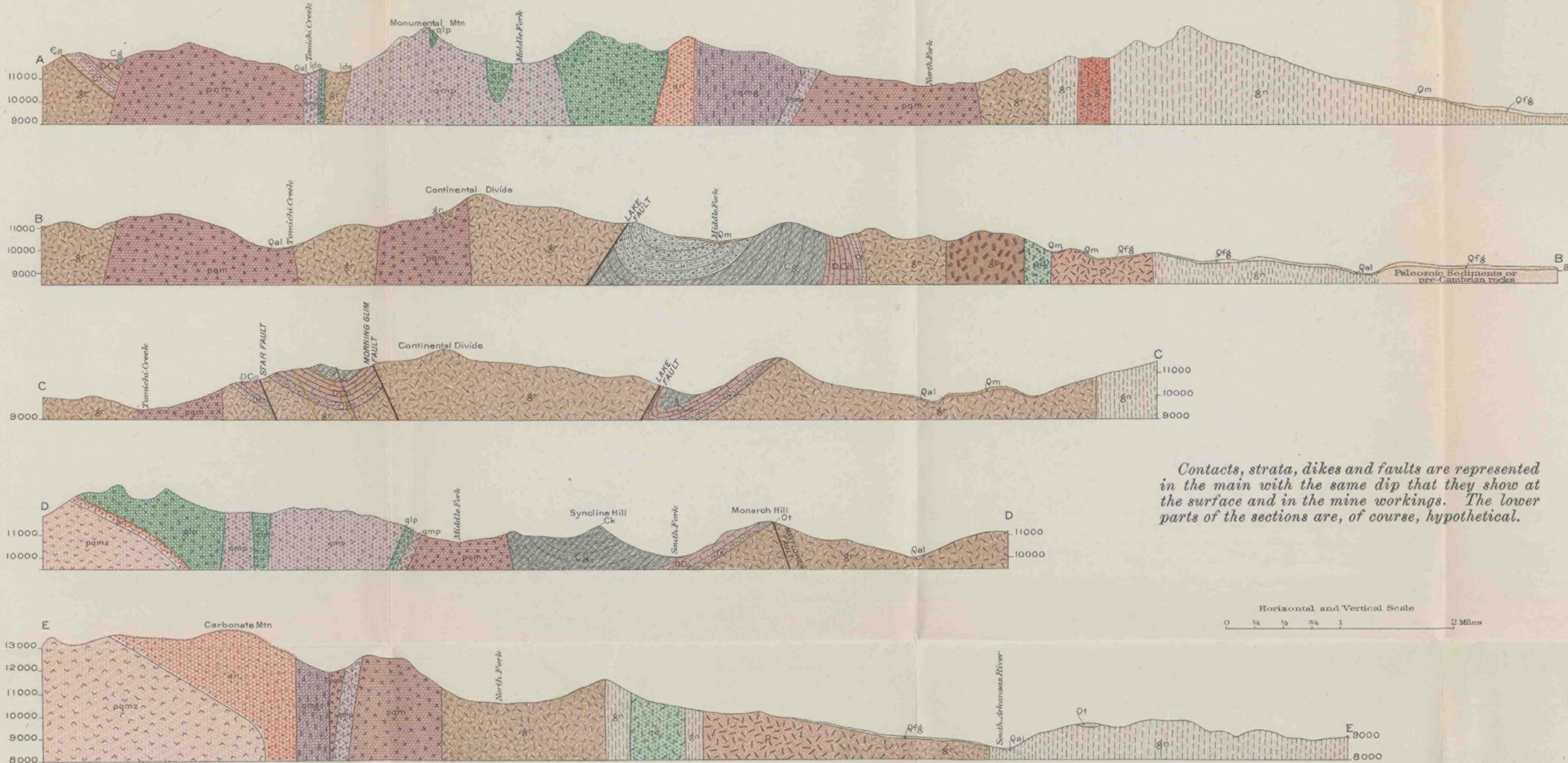
Geology by R. D. Crawford, assisted by R. M. Butters, R. C. Coffin, and P. G. Worcester. Surveyed in 1909-10.

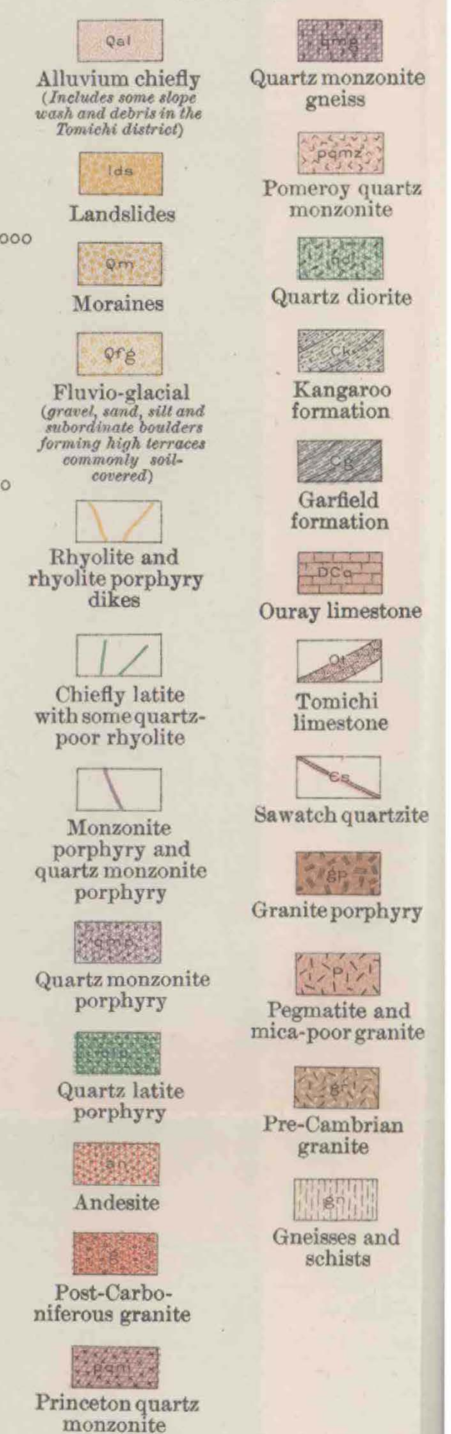
Scale 1/62500 or approximately 1 inch to 1 mile

Contour interval 100 feet
Datum is mean sea level

COLORADO STATE GEOLOGICAL SURVEY
R. D. GEORGE, DIRECTOR

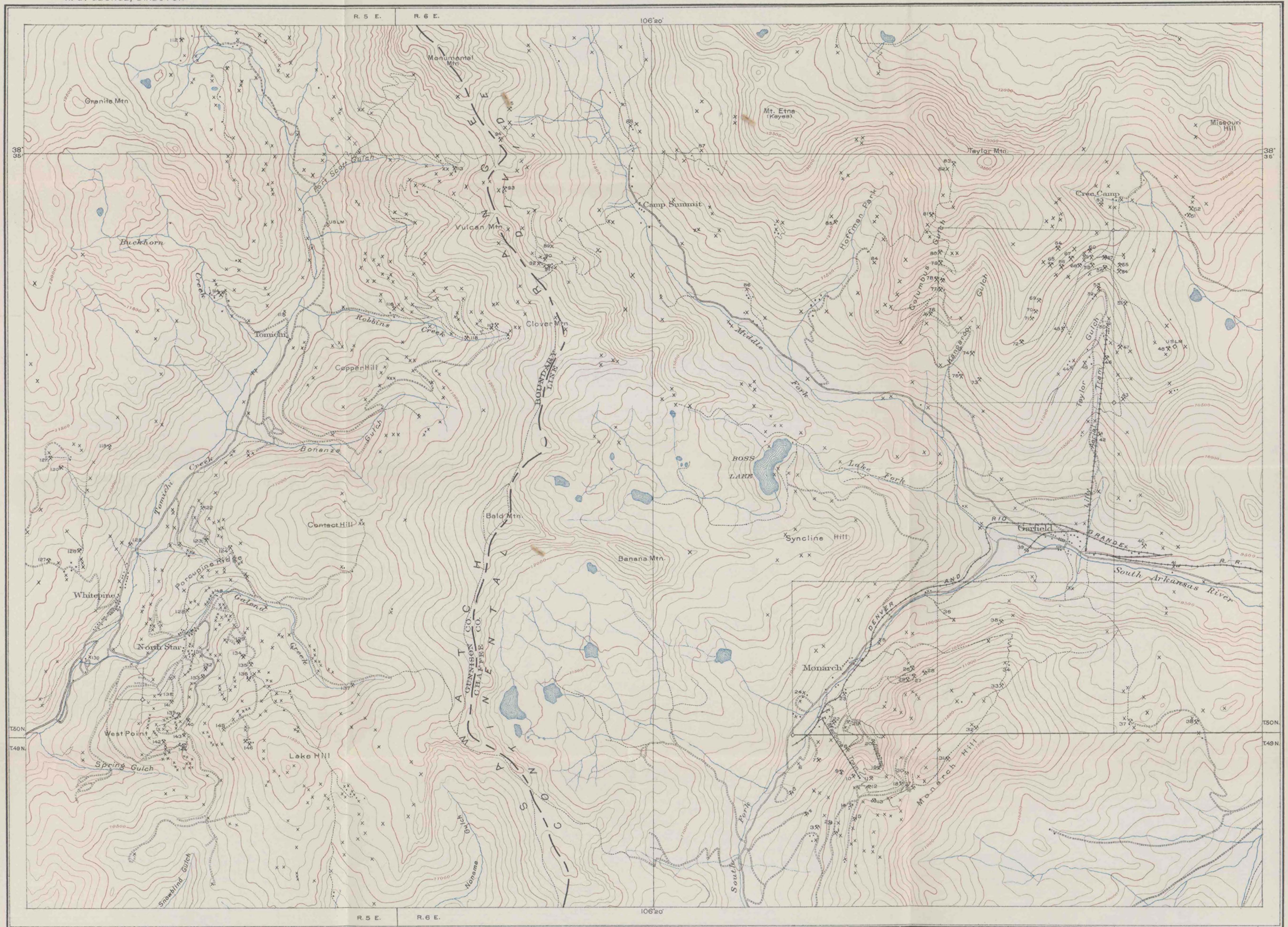
BULLETIN 4 PLATE III





GEOLOGIC SECTIONS OF THE MONARCH AND TOMICHI DISTRICTS ALONG THE LINES A-A TO E-E ON PLATE II

COLORADO STATE GEOLOGICAL SURVEY
R. D. GEORGE, DIRECTOR



LEGEND

Mine

Prospect or Quarry

Land corner known

MINES, QUARRIES AND PROSPECTS

1 Silent Friend No. 1
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Surveyed in 1909-10.

MONARCH-TOMICHI SPECIAL TOPOGRAPHIC MAP

Scale $\frac{1}{25000}$ or approximately $2\frac{1}{2}$ inches to 1 mile

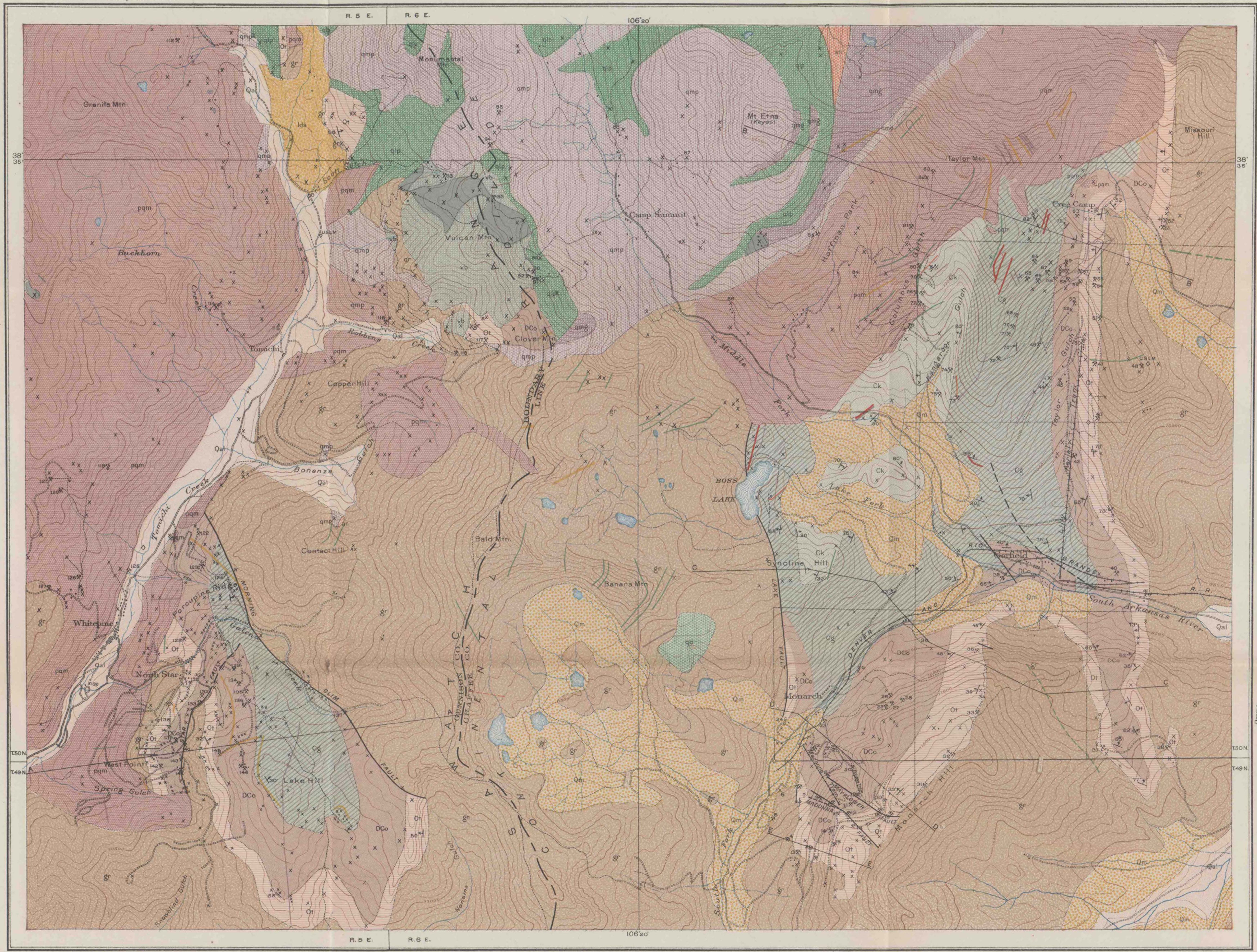
0 ¼ ½ ¾ 1 2 Miles

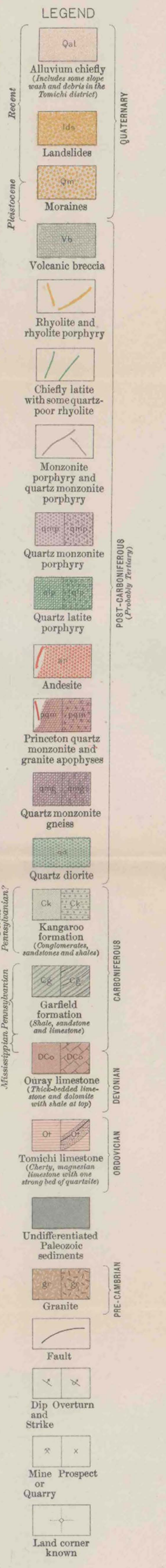
0 ½ 1 2 Kilometers

Contour interval 100 feet
Datum is mean sea level

COLORADO STATE GEOLOGICAL SURVEY
R. D. GEORGE, DIRECTOR

BULLETIN 4 PLATE V





MONARCH-TOMICHI SPECIAL GEOLOGIC MAP

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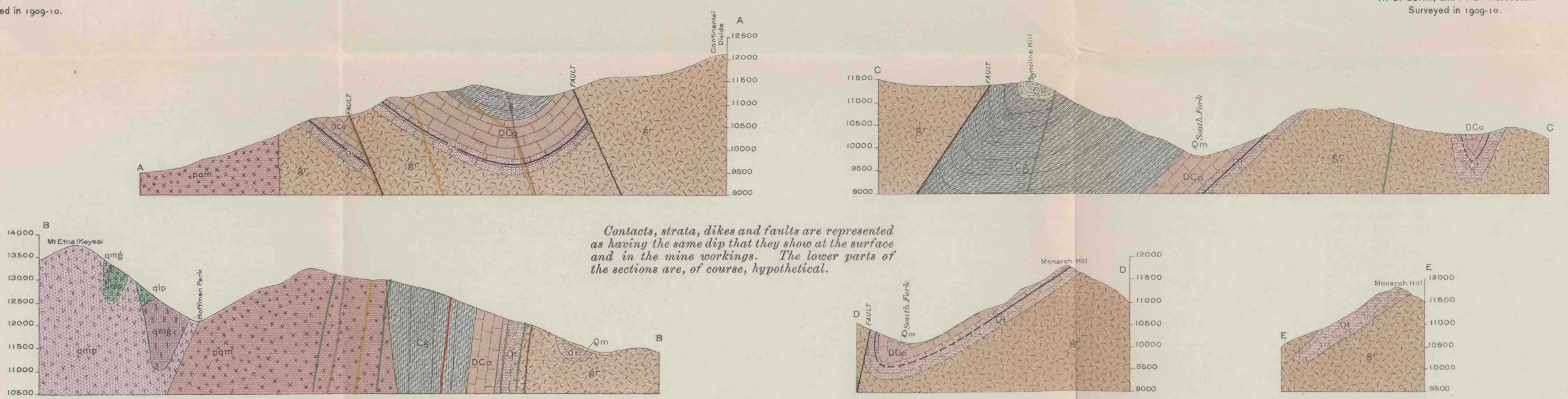

Contacts, strata, dikes and faults are represented as having the same dip that they show at the surface and in the mine workings. The lower parts of the sections are, of course, hypothetical.

Horizontal and Vertical Scale $\frac{1}{125000}$ or approximately $2\frac{1}{4}$ inches to 1 mile

0 — 1 — 2 Miles

0 — 1 — 2 Kilometers

Contour interval 100 feet
Datum is mean sea level

PLAN OF MADONNA MINE