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R. D. GEORGE, State Geologist

BULLETIN 10

GEOLOGY AND ORE DEPOSITS

OF THE

GOLD BRICK DISTRICT

COLORADO

By

R. D. CRAWFORD and P. G. WORCESTER

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GEOLOGICAL BOARD

LETTER OF TRANSMITTAL

STATE GEOLOGICAL SURVEY,
UNIVERSITY OF COLORADO, December 2, 1916.

Governor George A. Carlson, Chairman, and Members of the Advisory Board of the State Geological Survey.

GENTLEMEN: I have the honor to transmit herewith Bulletin 10 of the Colorado Geological Survey.

Very respectfully,
R. D. GEORGE,
State Geologist.

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ILLUSTRATIONS

GEOLOGY AND ORE DEPOSITS
OF THE
GOLD BRICK DISTRICT, COLORADO

INTRODUCTION

BY R. D. CRAWFORD

GEOGRAPHIC POSITION AND NAMES

The Gold Brick mining district is in the eastern part of Gunnison County, Colorado, and west of the Continental Divide. The area covered by the present report—a little more than 65 square miles—includes the Gold Brick district and part of the Quartz Creek and Box Canyon mining districts. Practically all of the territory south of Quartz Creek shown on the accompanying maps is in the Box Canyon district. The Quartz Creek district is east of the watershed that separates the drainage basin of Armstrong Creek from the drainage basin of Gold Creek. The approximate position of the boundary line between the Quartz Creek and Gold Brick districts is shown on the map of mining claims (Pl. III, in pocket).

Ohio City, on what was a few years ago the South Park division of the Colorado and Southern railroad, is the nearest shipping point and the only incorporated town in the district. Ohio City is the corporate name of the town; Ohio is the United States Government name of the post-office. The narrow-gauge railroad from Pitkin to Ohio City and thence to Parlin is now operated as part of the Denver and Rio Grande system, and joins the main narrow-gauge line of the Denver and Rio Grande railroad at Parlin.

With a single exception the geographic names used in this bulletin are local names given by the early settlers. Ohio Creek is the name that was long used for the stream that empties into Quartz Creek at Ohio City, but the Colorado Legislature, in 1911, changed the name of this stream to Gold Creek. A few faults are specifically named in this report for convenience of reference.

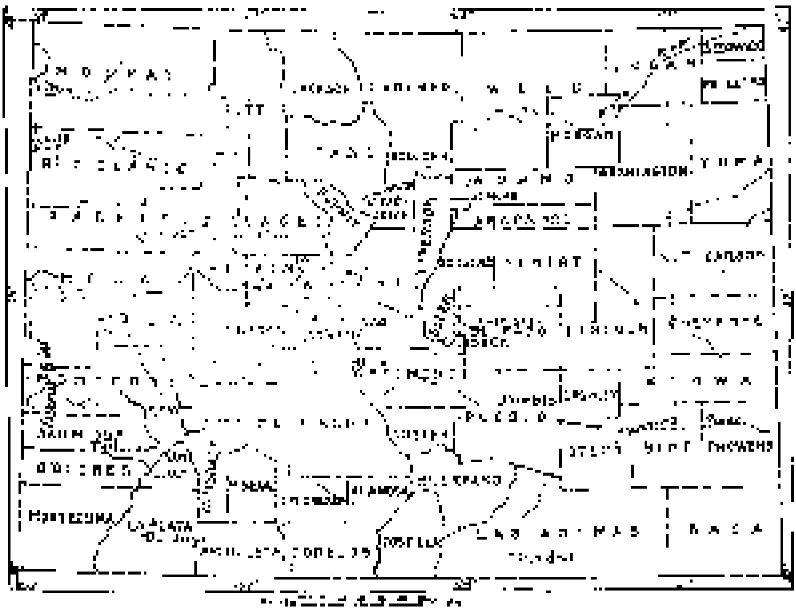


Figure 1.—Index map of Colorado, showing position of the Gold Brick district

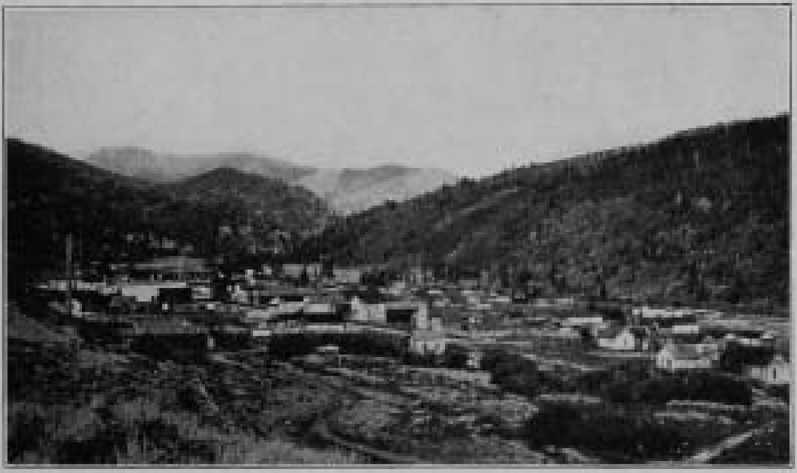
FIELD WORK AND ACKNOWLEDGMENTS

The topographic and geologic mapping of the Gold Brick mining district was done in the summers of 1911 and 1912 by a single party which spent about two months each season in the field. R. C. Coffin had charge of the topographic work, and later prepared the topographic map for the engraver. He was assisted in the field in 1911 by R. G. Coffin, A. W. Lauer, and G. B. Warner. In 1912 topographic mapping was done only by R. C. and R. G. Coffin, who also gave considerable time to geologic work.

A considerable area was mapped geologically in 1911 by R. C. Coffin and the writer when the latter spent about one month in the field. P. G. Worcester was engaged in geologic mapping throughout the field season of 1912, and has written the chapters on physiography and stratigraphy for this report. R. M. Butters was engaged in stratigraphic work between three and four weeks in 1912. Besides a month in 1911, the writer was engaged in geologic work in the district two weeks in 1912 and several days in 1914.

For the control of the topographic map two base-lines were carefully measured. The first—about 7,400 feet long—was measured along the railroad tangent that passes through Ohio City and westward beyond this tangent. The second base-line—about 4,000

A. OHIO CITY FROM THE SOUTH



B. PITKIN FROM THE WEST

feet long—was measured along the ridge between Boulder and Comanche creeks. From these base-lines a system of triangulation was carried over the entire area mapped. This system was tied to the Hayden Survey control by the occupation of Mount Ouray (from which several points in the district are visible) and by resection on Mount Harvard. The triangulation was checked by sights to Princeton, Antero, and Shavano mountains.

Traverse plane-tables with open-sight alidades were used for both triangulation and traverse. All the high points in the district were occupied. Traverses were run along all the high ridges, along all the roads and many trails, and along most of the gulches. The plane-tables were oriented by fore and back sights, except locally in thick timber where Brunton compasses were used.

Elevations were determined by aneroid readings, the aneroids being set at Ohio City and Pitkin, whose altitudes had been determined by the railroad survey. Throughout the course of the work the aneroids were frequently checked. Probably but few contours are in error more than two intervals.

Geologic mapping closely followed the topographic mapping by using for a base map a tracing of the plane-table sheets. Brunton pocket transits were used to get bearings, while distances were determined by pacing and by resection and triangulation with the aid of the Brunton transit. Certain parts of the district have not been traversed by the writer who, in the preparation of his part of this report, has used the field notes of other members of the party.

Professor Junius Henderson identified the fossils collected. The drafting for the zinc etchings was done chiefly by J. H. Wallace. The mine maps used in this bulletin are reductions from large-scale maps furnished by the mine owners.

The field party received much valuable assistance from mine owners, officers of mining companies, and miners, who generously gave their time to show the mines and did everything in their power to facilitate the work. Others to whom especial thanks are due are: Mr. W. H. Eckbert, for his permission to reproduce in this bulletin the mining-claim map that he had prepared; Mr. Louis Johnson, who identified for the writer many old mines on the ground; Mr. H. S. Roe, who showed the workings of the Cortland mine in so far as they were accessible and who furnished much information of the early history of the district; and Mr. S. M.

Tarkington, who supplied many geographic names used by the early settlers.

HISTORY OF MINING[1]

In 1879 Jacob Hess, a prospector, miner, and assayer, who was camping near Pitkin, found at the mouth of Ohio Creek—now Gold Creek—a boulder which assayed 900 ounces silver per ton. He moved his camp to Ohio Creek, and became the first settler of the village now known as Ohio City, but originally called Eagle City. The camp flourished throughout the year 1880 when many men were prospecting the surrounding hills. Many claims were located, but only a few of the claims located in 1879 and 1880 became producers. Most of the good discoveries were made later. In 1881 Ohio City was surveyed and platted; and the Denver, South Park and Pacific railroad was built through the town in 1882.

There was much activity in the district through the eighties and early nineties when many mines were producing ore from workings that were mostly less than 300 feet in depth. Considerable crude ore was shipped to the smelters, but several stamp mills on the creeks near the mines turned out both bullion and concentrates.

In the nineties when the price of silver fell and the easily mined, known ore bodies near the surface had been largely worked out, most of the mines were closed. In 1898 the Cortland mine in McIntyre Gulch was the only mine of the district in operation. Gold Creek, then called Ohio Creek, was almost deserted.

In the face of these discouraging conditions, the three Carter brothers—at that time Harvard University students—came to the district and spent their summer vacations in driving through gneiss and schist, by hand drilling, a crosscut tunnel to develop at depth several known veins. This enterprise was continued by the subsequently organized Carter Mining Company of which Mr. Carroll M. Carter, one of the three brothers, is president. During the past year this company has been mining and milling ore from the old Volunteer vein opened by a raise and crosscuts.

The Raymond Consolidated Mines Company, under the management of the late Mr. E. M. Lamont, opened a number of ore-bearing veins by driving a crosscut tunnel. For several years this company has been successful in mining ore in these veins at a much greater depth than any of them had been formerly worked. Most

[1]This report was written in the summer of 1915, and does not record the most recent mining activities of the district.

of the ore is treated in the company's mill which turns out both bullion and concentrates.

The Colorado Smelting and Mining Company, of which Mr. A. E. Reynolds is president, acquired a large tract that includes the old Sacramento and Silver Islet mines, and opened a good vein—the Gold Links—in a crosscut tunnel. This mine produced ore nearly or quite continuously from October, 1908, to December, 1912. Some of the high-grade ore has been shipped directly to the smelter, but most of it has been milled in the company's amalgamating and concentrating mill near the portal of the tunnel. The mine is now (1915) being worked under lease.

The three tunnels mentioned—all starting at Gold Creek and running eastward—have done a great deal to develop the veins at a much greater depth than was attempted in earlier years. Meanwhile several other mines have been operated at intervals and have produced shipping ore from comparatively shallow workings. The total output of the district is unknown, but the production of a few mines is stated in the section in which the mines are described.

WATER SUPPLY AND TIMBER

Quartz Creek and Gold Creek furnish abundant water throughout the year for milling purposes. Water power is used to a small extent throughout the year and to a greater extent during the summer by the Gold Links, Raymond, and Carter mines and mills. Other streams that flow through a considerable part or all the year are Willow, Comanche, Boulder, Lamphier, Jones, Dutch, McIntyre, Revenue, Freeman, and Roosevelt creeks.

Not only is the timber supply adequate for mining requirements for many years to come, but there are still to be found many trees suitable for lumber. Sawmills formerly were in operation on Comanche and Gold creeks. Many carloads of poles, to be used as props in coal mines, have been cut south of Quartz Creek and shipped out of the district.

MILLING

The only mills in this district that have treated large quantities of ore in recent years are the Gold Links, Raymond, and Carter mills. All are stamp-mills equipped with both amalgamating plates and Wilfley tables. The pulp passes over the plates, which remove part of the values, and thence goes to the tables for concentration.

PREVIOUS GEOLOGIC WORK AND LITERATURE

There are but few published accounts that deal with the geology and mining of the Gold Brick district. Ore was not discovered here until after the work of the Hayden Survey, in Colorado, was completed, and that organization appears not to have made a detailed study of the region. In 1908 J. M. Hill, of the United States Geological Survey, examined the mines of the Gold Brick and other districts of Gunnison County. His report, which includes a sketch map of the geology, is given in the list below. Several references to the district and to individual mines are found in successive volumes of Mineral Resources of the United States, published by the United States Geological Survey, and in the annual reports of the Director of the Mint.

Published papers that in part or entirely deal with the Gold Brick district are listed below.

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CHAPTER I

PHYSIOGRAPHY

BY P. G. WORCESTER

TOPOGRAPHY

RELIEF

The district is one of high relief. Its lowest point is on Quartz Creek, a few miles southwest of Ohio City, where the elevation is about 9,200 feet. Mount Henry, the highest peak in the district, is, according to carefully checked aneroid readings, about 13,100 feet high. Fairview Mountain and the peak just west of Mount Henry are slightly less than 13,000 feet high.

The topography of all of the northern part of the region is very rugged. The valley walls are steep and the ridges are ragged. In the central and southern parts of the area the mountains are not so high, the slopes are more gentle, and the region as a whole is more mature.

North and west of Ohio City most of the longer valleys are cut along the strike of the gneissoid and schistose structure of the rocks. This is the only region where rock structure has governed to any extent the development and direction of the streams.

The topography of the district, considered as a whole, is youthful.

DRAINAGE

Springs.—There are many springs in the district, especially around Fossil Ridge, and in the other regions of sedimentary rocks. Most of these are in the limestones, and probably are of the fissure spring type.

The gulches east of Gold Creek and south of Quartz Creek also have a good many springs, and it is safe to assume that, except for the streams fed by lakes, wherever a permanent stream appears on the map its source is in a spring.

Streams.—Most of the streams are fed by lakes or springs and are permanent. They furnish an abundant supply of water for the mining, milling, and agricultural pursuits of the district. In the southern part of the area there are a good many intermittent streams, but they are in the region where neither mining nor grazing is at present extensive.

Lakes.—Glacial lakes occur in nearly every cirque in the district. Some of the lake basins were formed by the damming of valleys by terminal moraines, but nearly all east of Fossil Ridge were formed by the glaciers which gouged depressions out of the solid rock.

As factors in conserving and insuring a sufficient flow of water in the creeks for mining operations, the glacial lakes are of considerable importance.

Swamps.—West of Fossil Ridge in the glaciated regions there are a good many small swamps and bogs which are due directly to the filling of glacial lake basins by vegetable growth.

For more than 2 miles east of Ohio City the meadows have been flooded and swamps formed by beaver dams built along Quartz Creek. More than a square mile has been partially covered in this way, although usually the water is low enough in the summer to allow the swamp grass to be cut. The beaver is unquestionably a nuisance here. It is safe to say that if he were exterminated, the meadows along Quartz Creek would soon increase in value.

GLACIATION

At the present time the snow lies until late in the summer on the flanks of Fossil Ridge and in equally favorable situations on the other high ridges and mountains of the district. It is evident that a comparatively slight increase in precipitation, coupled with a slight decrease in the annual temperature, would result in the formation of perennial snow fields which, in turn, would furnish the necessary supply of ice for glaciation similar to that which occurred in the Pleistocene epoch.

Fossil Ridge at that time was undoubtedly covered with a great snow field of unknown but considerable thickness. Tongues of ice extended outward from the snow field as valley glaciers. These were variable in length. The distance from the cirque at the head of the west fork of Gold Creek to the lowest limit of the moraine in that valley is about 4 miles. This is one of the best examples of a glaciated valley in the district, and it probably shows the average distance of glaciation away from Fossil Ridge.

CIRQUES

Fossil Ridge is practically surrounded with cirques, which have been more or less modified, since they were formed, by weathering and by stream erosion. They were readily carved out of the shales and limestones, and some of the largest cirques occur in regions of sedimentary rock. It is evident that the sedimentary rocks covered a wider area before glacial erosion took place than they do now.

On account of the structure of the sediments east of Fossil Ridge, natural amphitheatres are left with terraces which extend from the bottom nearly to the top. The harder limestones form the floor of the terraces, while the shales form the steps from one limestone bench to another. (See Pl. VI, A.)

Most of the cirques still have glacial lakes, but two or three have been completely drained, and all traces of glaciation have been removed except the characteristic "U" shaped valleys. Comanche Gulch is a good example of this type of valley.

BOULDER FIELDS

A great boulder field occurs about a mile south of the northern border of the district and three-fourths of a mile west of Gold Creek. The boulders are scattered over an area of nearly half of a square mile and some of them are very large. Local boulder fields occur in the valleys west of Fossil Ridge, but they are small compared with the one just mentioned.

MORAINES

These deposits are described under Quaternary Deposits and need not be discussed here, except to note the morainal topography north, east, and west of Fossil Ridge. Lateral moraines in the west tributaries of upper Gold Creek are several hundred feet high and extend parallel with the trend of the valley for 2 or 3 miles. They are by far the best examples of lateral moraines in the district. Both terminal and lateral moraines are found in the valleys west of Fossil Ridge.

CLIMATE

It has been impossible to get records that would furnish very accurate data regarding the climate of this district. Records from Gunnison, a few miles south; Crested Butte, northwest; and Pitkin, just east of the area, give the best comparative data. The stations at Pitkin and Crested Butte have only recently been established, and the records now at hand probably do not represent the average conditions that would prevail for a greater number of years.

The following summary is taken from the Summary of Climatological Data for Colorado for 1914, published by the U. S. Weather Bureau, Feb. 15, 1915:

Table of Climatic Data for 1914

	Precipitation	Temp.	Warmest month	Coldest month
Pitkin	19.82 in.	36°		
Gunnison	13.39 in.	35.6°	62.6°, July	7.4°, Feb.
Crested Butte	33.27 in.	33.6°	55°, July	9.2°, Dec.

Because of the high relief the climate of the district varies greatly in different places.

The precipitation averages from about 15 to 25 inches a year. There is a very heavy snow fall, but it has not been possible to get the exact figures. At Crested Butte, in 1914, the snow fall was 187.0 inches. Fossil Ridge is about 4,000 feet higher than Crested Butte, and it is probable that the snow fall is at least as great, if not greater than in that district.

SOIL

Fertile soil is found along Quartz Creek and in the lower portions of most of the larger valleys. It also is found on many of the gentle, non-glaciated slopes. Some of the moraines have been weathered until a residual soil is left, but such soil is usually found some distance from the heads of the glaciated valleys.

On the east slopes of Fossil Ridge very little good soil is found, either on the steep slopes or in the amphitheatres. The shales and limestones disintegrate rapidly to form soil, but the weathered material has been washed away or dissolved about as fast as it has formed.

In the valleys and on the gentle slopes west of Fossil Ridge there is a heavy soil covering which, below timber line, supports luxuriant vegetation and a heavy growth of timber. In Chicago Park and in other similar areas south of Fairview Mountain and east of Gold Creek the soil is good, and native grass is found which is suitable for grazing and, in some cases, for making hay which is the principal crop of the district.

In the southwestern part of the area, away from the creeks, the soil is poor.

TIMBER

The altitude of timber line is about 11,600 feet. Below this altitude, where the soil is fertile and the ground water sufficient, there is a good growth of timber.

On the south side of Quartz Creek; in Dutch and Jones gulches; along Gold, Willow, and Alder creeks; in the neighborhood of Chicago Park; and, in fact, throughout the district, except in the southwestern corner and in the high, recently glaciated regions in the northern part of the area, timber is abundant.

Pine, spruce, aspen, and willow are the principal varieties found in the district. The first two predominate.

CHAPTER II

OUTLINE OF GEOLOGIC HISTORY

BY R. D. CRAWFORD

The legible geologic history of the region begins with a pre-Cambrian epoch of unknown duration. During this epoch, in addition to being folded and possibly faulted, the then existing sediments and possible igneous rocks underwent profound metamorphism through which were developed quartzite, schists, and gneisses. Following this was a period—probably of considerable length and beginning before regional metamorphism was completed—of igneous intrusion, when the older rocks were invaded by diorite and related rocks and by granite.

There is some evidence that the intrusion of granite was accompanied or closely followed by the formation of ore-bearing mineral veins.

The plutonic rocks and invaded metamorphic rocks were subsequently exposed to erosion through a long period which may or may not have been interrupted by epochs of sedimentation. The erosion period probably began in pre-Cambrian time and closed with early Upper Cambrian.

In supposedly Upper Cambrian time the sea advanced over the region when the quartz sand of the Sawatch quartzite was deposited. This was followed by successive emergences and submergences through the Paleozoic era certainly until as late as Pennsylvanian (Upper Carboniferous) time and probably as late as the end of the Paleozoic era.

Judging from what is known of the geologic history in the Elk Mountains region toward the northwest it seems probable that the Gold Brick region was under water through at least part of the Mesozoic era, but there is no sedimentary record later than Pennsylvanian within the district. Subsequent to the deposition of Pennsylvanian sediments the region was subjected to strong compressive forces which developed folds in the sedimentary beds and faulted both Paleozoic and pre-Paleozoic rocks.

Still later, minor intrusions of porphyries cut through nearly all varieties of the older rocks. These intrusions resulted in slight metamorphism of limestone with which they came into contact. It is very probable that a small amount of ore deposition accompanied or closely followed the intrusion of porphyry.

Beginning at an unknown time subsequent to Pennsylvanian the surface has been exposed to erosion which has removed the Paleozoic and possibly later sediments from most of the region, and has cut deep valleys in the pre-Cambrian rocks. The work of running water has been modified and interrupted by local glaciers in the higher parts of the region.

Besides erosion with attendant deposition of alluvium along stream channels, recent time has been characterized by the work of ground waters which includes oxidation of the primary sulphides of the ore bodies.

CHAPTER III

PRE-CAMBRIAN METAMORPHIC ROCKS

BY R. D. CRAWFORD

The pre-Cambrian metamorphic rocks of the Gold Brick district include gneisses, schists, and quartzites which, with few exceptions, it seemed impracticable to map separately. There are also within the metamorphic area a few small intrusions of dioritic rocks not shown on the map. Furthermore, the boundary between the metamorphic and igneous rocks as given is in places only approximate because of the numerous intrusions in the metamorphic area near the border and large inclusions of gneiss and schist in the igneous rocks. This is true of the region northwest of Ohio City, where the rocks along the border zone constitute a gigantic breccia. However, throughout a large part of the district the contact between igneous and metamorphic rocks is well defined. The area mapped as gneiss between Fairview Mountain and Gold Creek probably contains some gneissoid granite.

The rocks considered in this chapter are the oldest to be seen in the region, and are cut by granite and diorite which are probably also of pre-Cambrian age. The character of the composition of the quartzites, most of the schists, and a small part of the gneiss indicates their sedimentary origin. Certain varieties of the gneiss are evidently metamorphosed igneous rocks that were intruded prior to the final stage of regional metamorphism.

With the exception of some of the later quartzite and a small part of the intrusive rocks, the entire series has been subjected to profound metamorphism which has almost completely obliterated the original structure. The parallelism between the quartzite beds and structure planes of the inclosing schist indicates that the planes of schistosity are at least in part parallel to the former stratification planes.

These planes now strike for the most part between N. 70° E. and N. 60° W. North of Quartz Creek the strike is generally 10°

to 40° east of north. South of the same creek the strike will average about N. 45° W. The dip is almost universally westward at an angle of 45° to nearly 90° with a probable average of 60°.

The rocks described below include all the regional-metamorphic types recognized in the district, but there are also several intergradations and sub-varieties.

MICA SCHIST

Mica schist is one of the commonest metamorphic rocks of the region. It is almost uniformly fine grained and commonly light gray. Occasional bands are dark gray on account of the high proportion of biotite. The schist varies in composition from a nearly pure quartz rock to one whose principal component is mica. In places the mica is exclusively muscovite, usually in fine flakes of sericitic character. In other places the principal mica is brown or black biotite. Chlorite is not infrequently associated with the biotite. Fine-granular quartz is the only other essential component ordinarily present except in the cordierite-bearing and garnet-bearing schists described below. The microscope fails to disclose other essential components.

Though the mica schist is everywhere thinly laminated it rarely shows more than moderate contortion.

CORDIERITE-MICA SCHIST

There is a considerable body of "spotted schist" in the northern part of the area mapped, principally between Henry Mountain and Lamphier Lakes. Glacial boulders of the same rock are common in the valleys of Gold Creek and its branches. Though the schist varies in texture and mineral composition it commonly contains cordierite or material replacing cordierite in grains or patches sufficiently large to be noticeable, if not conspicuous, in hand specimens.

For the most part the planes of schistosity strike N. 65° to 70° E. and dip southward at an angle between 40° and 75°.

A striking feature of the least weathered schist is the abundance of cordierite which is mostly in elongated subhedrons or pseudophenocrysts varying greatly in size and number from place to place. Those seen with the naked eye have dimensions ranging from 1/32 by 1/16 inch to ¾ by 2½ inches. The largest pseudophenocrysts may be seen on and near the divide where it is crossed by the trail leading from Lamphier Lakes to the Bornite claim.

The cordierite is very dark gray and most conspicuous on faces of freshly broken rock or on the surface of waterworn boulders. In places the cordierite is replaced wholly or partly by a black substance or by a mixture of this material and brown limonite. Where fresh the cordierite has a glassy luster and not infrequently shows a distinct cleavage. This mineral varies in quantity from about one-third of the rock mass to an almost negligible component.

The rock as a whole is gray of various shades, perhaps most commonly silver-gray. The composition, exclusive of the cordierite content, is that of a normal mica schist, typically a muscovite schist. Finely flaked muscovite, near sericite, is universally present though variable in quantity. Locally biotite crystals 1 to 3 mm. in diameter are present in a cordierite-poor variety of the rock. Quartz is scarcely to be detected in most hand specimens, but occurs in masses approximating the dimensions of cordierite grains where the latter mineral is most coarsely crystallized.

The microscope shows, in addition to the minerals mentioned, apatite and magnetite. Both of these minerals are common throughout the rock, but are especially plentiful as inclusions in the cordierite. The apatite is commonly in small prismatic crystals; the magnetite occurs in octahedrons and formless grains.

Quartz and muscovite make up the greater part of the rock mass. Biotite is sometimes seen in minute flakes, but oftener in larger subhedrons that inclose other minerals of the rock. Muscovite occurs for the most part in small flakes with nearly parallel orientation. With the small grains of quartz are a few grains of an optically negative biaxial mineral, probably cordierite.

The pseudophenocrysts of cordierite commonly inclose in varying quantity quartz, muscovite, apatite, and magnetite. Pronounced, numerous, and comparatively large pleochroic halos may be seen in some crystals.

GARNETIFEROUS SCHIST

Three small exposures of garnet-bearing schist have been observed within the area mapped. One is near Boulder Creek and about half a mile west of the Gold Links mine. The second is a few hundred feet southeast of the same creek and about three-fourths of a mile south of Boulder Lake. The third exposure is about three-fourths of a mile southeast of Boulder Lake.

The rock of the first named area contains numerous reddish garnet crystals one-eighth inch to one inch in diameter. Practically all the crystals have well developed faces of the rhombic dodecahedron, though many are elongated in the direction of an axis of trigonal symmetry and have a hexagonal aspect. Many of the distorted crystals are oriented with their direction of elongation nearly or quite normal to the planes of schistosity.

The bulk of the rock is biotite, chlorite, and quartz in varying proportions. The microscope shows many small grains of black iron ore scattered throughout the rock and inclosed by the garnet. The garnet is isotropic and, excepting the inclusions of ore, is practically homogeneous. It is shown by qualitative tests to be almandite carrying a little calcium, magnesium, and manganese.

The garnetiferous schist of the last-mentioned area is similar to the rock just described, but no pronounced distortion of the crystals was noticed. The schist of this locality is in contact with the pyroxene-bearing quartzite described in another section.

The garnet-bearing schist of the area due south of Boulder Lake is different from the variety described. It commonly contains many dark bluish-gray, roundish garnet grains that in places make up about half the rock volume. A small part of the rock carries reddish garnets having a shape like that of the bluish variety. The garnet grains, which are commonly three-eighths to five-eighths inch in diameter, show no crystal faces in hand specimens and only traces of crystal outline in thin sections. Since this mineral is very resistant to weathering the grains stand out conspicuously with a wartlike appearance on the weathered surface of the rock. Individuals thus exposed not infrequently reflect the light from interrupted plane surfaces that suggest cleavage. This phenomenon, the bluish color, and the apparent absence of crystal form might easily lead one to mistake the mineral for cordierite.

In thin section the garnet is colorless and isotropic. It invariably incloses microscopic grains of quartz and black iron ore. In some slides many small flakes of colorless amphibole extinguishing at about 22° are inclosed by the garnet. In others biotite in small flakes but no amphibole, is inclosed by the garnet. Chemical tests show the presence of a little manganese, ferrous iron, and aluminum in addition to much calcium and ferric iron. The garnet is evidently andradite in which a small part of the ferric iron is replaced by aluminum.

The matrix in which the garnets are embedded is composed chiefly of biotite, amphibole, and quartz, with a small amount of black iron ore. In some specimens biotite is the most abundant mineral of the matrix; in others amphibole exceeds the biotite in amount. The amphibole is partly a colorless variety and partly green hornblende.

AMPHIBOLE SCHIST

The metamorphic rocks of the region under consideration include at least two distinct types of amphibole schist, namely, hornblende schist and anthophyllite schist. Each of these presents several varieties, and it is not improbable that other types exist here.

HORNBLENDE SCHIST

While the several varieties of this schist are alike in having a finely-laminated schistose structure, they differ greatly in the size of the component grains which vary from a small fraction of an inch to an inch in length. Black hornblende is the most abundant constituent and locally composes all but a small fraction of the rock. In places hornblende is accompanied by considerable biotite. In some specimens quartz is not found; in others it forms nearly half the rock volume. Epidote—perhaps an alteration product—is locally abundant. The microscope discloses considerable magnetite and an occasional feldspar grain.

ANTHOPHYLLITE SCHIST

Several specimens of anthophyllite schist were collected on mine dumps in Jones and Dutch Flat gulches. The greater part of the rock is composed typically of radial aggregates of gray anthophyllite whose cleavage faces are one-half inch to one inch long. Green chlorite with a little quartz fills the interspaces among the anthophyllite aggregates. Some specimens show alteration to talc and limonite.

Andalusite is the dominant mineral of a very dark gray specimen picked from a dump in Dutch Flat Gulch. This variety contains aggregates of black biotite and small aggregates of anthophyllite. The latter mineral is very dark gray inclining to black. Individual cleavages are one-fourth to one-half inch long. The andalusite is dark bluish-gray and entirely without crystal outline. Small fractures in the rock are filled with pyrite.

In thin section a small amount of quartz is seen in addition to the minerals named above. The andalusite is colorless in thin section and poikilitically incloses both biotite and anthophyllite. The anthophyllite is distinctly pleochroic: X = yellow-white; Y = faintly bluish-gray, almost colorless; Z = blue-gray.

Another specimen from Dutch Flat Gulch contains coarsely crystallized, light-gray anthophyllite with dominant dark bluish-gray andalusite.

QUARTZ SCHIST

White, finely laminated, fine-grained quartz schist forms at least one wall of each of several metalliferous veins. This schist is found in comparatively small quantity; observed individual seams do not exceed three or four feet in thickness.

The rock splits easily along parallel planes. Cleavage surfaces show considerable finely flaked sericite. Under the microscope quartz is seen to be the most important constituent by far; with it are a few grains of feldspar and considerable sericite. Crystals of pyrite—probably a replacement product—are found adjacent to the ore bodies.

The schist is quartzitic in composition, but differs from quartzite in having a more or less slaty cleavage as a result of imperfect banding.

GRANITIC GNEISS

This gneiss of uncertain origin and having nearly the composition of granite is found among the metamorphic rocks. It is medium to fine in grain and is gray of various shades. The principal components are orthoclase, microcline, quartz, biotite, and muscovite. The proportions between different minerals vary widely, but feldspar and quartz together generally, if not always, exceed the other constituents.

HORNBLENDE GNEISS

The greater part of the hornblende gneiss of this region is composed essentially of dominant hornblende and subordinate feldspar or feldspar and quartz. One variety carries a little biotite. A small amount of magnetite can be detected only under the microscope. Ordinarily the gneiss is syenitic or dioritic in composition. Since there is no sharp division between the dioritic gneiss and the gneissoid diorite the two cannot always be distinguished in mapping. Much of the gneiss is evidently of igneous origin. A small proportion is porphyritic, having feldspar phenocrysts in a very fine-grained groundmass. Varieties of the gneiss having a low feldspar content and more finely laminated structure than the average are closely related to the hornblende schist. The microscope shows that orthoclase and plagioclase are present in varying proportions.

COMMON QUARTZITE

Quartzite can be seen in many places within the area of regional metamorphism where it occurs generally in comparatively small masses intercalated with schist. It varies considerably in composition, color, texture, and degree of metamorphism. Practically all the quartzite considered here, like the schist with which it is associated, is demonstrably older than the bulk of the intrusive rocks of the region. No attempt was made to map separately the numerous small areas, but a few of the largest exposures of the quartzite that has undergone only moderate metamorphism are represented on the map.

The quartzite just mentioned is found chiefly south of Quartz Creek, but an outcrop of what is probably the same rock may be seen near the north boundary of the area mapped about half a mile east of Broncho Mountain. The largest body exposed, which can be traced a distance of nearly a mile and a half, from near the head of Revenue Gulch to near the mouth of Bluebird Gulch, probably has a maximum thickness of a few hundred feet.

This quartzite is medium grained, somewhat sandy in appearance, and has undergone metamorphism in but slightly greater degree than has local facies of the Sawatch quartzite. It is commonly light gray in color with a yellowish, brownish, or reddish cast varying with the kind and quantity of iron oxide contained. Locally it may be nearly white or dark bluish-gray. In places the rock carries much magnetite in small grains; some specimens show crystals of pyrite; limonite stain is common. The largest body of this quartzite is said to carry almost uniformly a small amount of gold.

The age of this quartzite has not been determined, but the comparatively low degree of metamorphism and the relation to other rocks would indicate that it is younger than the oldest quartzite of the region and older than the Sawatch quartzite. It is certainly older than the diorite with which it is in contact.

Other quartzites, not shown on the map, are exposed in many localities. Perhaps the largest observed outcrop is east of Lookout Mountain where one or more beds of quartzite may be traced more than half a mile. Here the quartzite is at least 20 feet thick.

Thinner beds may be seen not far northwest of Ohio City on the ridge between Illinois Gulch and Gold Creek. There are many outcrops south of Boulder Lake. About one-fourth mile southwest of the Sacramento mine a prospect hole has been sunk about 30 feet in a bed of quartzite that is at least 5 feet thick. Glacial boulders of similar quartzite are scattered west of Henry Mountain. It is probable that the several small bodies of quartzite shown on the map east of Lookout Mountain should be classed with the older, highly metamorphosed, unmapped quartzites.

These quartzites have all been thoroughly metamorphosed. The quartz has been universally recrystallized and forms interlocking grains that furnish little evidence, in their properties, of the clastic origin of the rock. These rocks are intercalated with and grade into schists, and are among the oldest rocks of the region. They are commonly bluish to purplish or reddish and of medium to coarse grain. Magnetite is often present in considerable quantity. Other subordinate components are muscovite, biotite, garnet, and pyroxene. An unusual variety of pyroxene-bearing quartzite is described below. The thin bed of quartzite southwest of the Sacramento mine carries considerable chalcopyrite.

PYROXENIC QUARTZITE

Pyroxene-bearing quartzite is exposed in two prospect holes about three-fourths of a mile southeast of Boulder Lake, and glacial boulders of the same rock are found near the mouth of Boulder Creek. Where exposed the quartzite bed is about four feet thick; it is vertical, and strikes N. 40° E. The rock grades on both sides into a quartz-mica schist which in places carries red garnet.

The quartzite is bluish, completely recrystallized, and closely resembles much of the oldest pre-Cambrian quartzite known in several districts of Colorado. Where examined the layers that carry no megascopic pyroxene have a maximum thickness of eight inches.

Green pyroxene is abundant in bands, lenses, and patches. The bands vary from a fraction of an inch to two inches wide, extend from several inches to several feet along the strike, and give way at the ends—commonly by gradation—to apparent pyroxeneless quartzite. The longest diameter of each of many of the lenses is less than two inches. The pyroxene is coarsely crystallized; individual grains having a diameter of two inches, as determined by the cleavage, are very common. Prismatic cleavage and basal parting are conspicuous, but crystal forms are very rare. Pyrite in formless grains may be seen in some of the pyroxene or in the adjacent inclosing quartzite. Though many large individual grains of pyroxene are free from megascopic inclusions the bands are likely to carry interstitial grains of quartz. In places the boundary between the pyroxene bands and inclosing quartzite is sharp; elsewhere pyroxene and quartz may be intermixed in any proportion.

As seen under the microscope the quartz grains of the quartzite are very irregular in outline and interlock with ragged edges. Undulatory extinction is general. Inclusions of pyroxene and amphibole are found in very small grains within the quartz. Minute grains of amphibole, in almost negligible quantity, are sometimes seen inclosed by pyroxene. The amphibole is pale green and extinguishes at about 22°.

The pyroxene is pale green and weakly pleochroic. It extinguishes at an angle of about 45°. The approximate birefringence—determined by comparing the highest interference color with that of quartz—is .024. Qualitative analysis of the mineral shows that it is a silicate of calcium, magnesium, ferrous and ferric iron, and aluminum. The pyroxene thus shows both optical and chemical properties of augite, and the rock could evidently be correctly designated augitic quartzite.

QUARTZITE CONGLOMERATE

On the steep slope about a mile northeast of Henry Mountain is an outcrop of quartzite conglomerate which somewhat resembles in appearance the granite with which it is in contact. The conglomerate is gray and contains many quartz pebbles about three-eighths inch in diameter. The matrix is chiefly fine-granular quartz with small flakes of muscovite. Besides these minerals there are patches of finely flaked biotite and a few grains of pale red garnet.

The interlocking of quartz with quartz and quartz with muscovite—seen only in thin section—shows that there has been complete recrystallization of the matrix. The quartz pebbles are also interlocked, in places, with the quartz of the matrix.

ANDALUSITE-QUARTZ ROCK

About a mile north of Lookout Mountain a streak of andalusite-quartz rock parallels the schistosity of the inclosing mica schist. The rock is very coarse grained and composed principally of andalusite and quartz in varying proportions. The andalusite is pink to reddish in color and shows distinct prismatic cleavage in hand specimens. This mineral is for the most part in prismatic crystals without crystal terminations. The largest observed individuals are an inch or more in length and have a width of about three-eighths of an inch. In thin section the andalusite is slightly pleochroic: X = pale yellowish-white; Y and Z = colorless.

Muscovite, biotite, chlorite, and magnetite accompany the andalusite and quartz in some specimens. The andalusite carries micropoikilitic inclusions of all the other minerals of the rock.

EPIDOTE ROCK

A short distance northwest of Ohio City is a streak very rich in epidote which, while perhaps not strictly a regional-metamorphic rock, deserves mention and is included here for want of a more suitable place in this bulletin. This streak can be traced several hundred feet and parallels the structure planes of the schist and quartzite which inclose it.

Though quartz is usually found in the rock some specimens are practically pure epidote. This mineral is yellowish-green and in part in crystals with indistinct terminations. Crystal individuals have a maximum length of two inches or more. Unfilled spaces among the crystals in some specimens and numerous crystal faces indicate the probable development of the epidote subsequent to the period of dynamometamorphism.

CHAPTER IV

IGNEOUS ROCKS[1]

BY R. D. CRAWFORD

In this chapter will be considered the several kinds of igneous rocks found in the Gold Brick district—both plutonics and rocks of minor intrusions. By far the greater number, if not all, of the plutonic rocks were intruded prior to the deposition of the Sawatch quartzite, and are probably of pre-Cambrian age. A possible exception is the quartz diorite, which may be post-Paleozoic. The dense porphyries and felsites, for the most part, are certainly younger than the Paleozoic sediments, and were probably intruded in Tertiary time when there was much igneous activity in the Rocky Mountain region.

GRANITE

In the district there are several varieties of granite that differ from one another in composition or texture, or in both composition and texture. The differences are for the most part unimportant, and in places there are gradations between different kinds. For these reasons it neither was feasible nor did it seem desirable to map separately the several varieties, excepting the one designated in this bulletin "Broncho Mountain granite."

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[1]The more technical parts of the rock descriptions, including descriptions of thin sections, are here printed in small type. Notes on the occurrence and relationships of the several rocks described, together with descriptions that may be used in the identification of the rocks in the field, are printed in the ordinary type.

For the classification and the descriptions of rocks without the aid of microscopic study and for the explanation of terms used to describe rocks, see the following:

"A Handbook of Rocks for Use without the Microscope," by J. F. Kemp: D. Van Nostrand Company, New York.

"Rocks and Rock Minerals, a Manual of the Elements of Petrology without the Use of the Microscope for the Geologist, Engineer, Miner, Architect, etc., and for Instruction in Colleges and Schools" by L. V. Pirsson: John Wiley and Sons, New York.

"Common Minerals and Rocks, their Occurrence and Uses" by R. D. George: Bulletin 6, Colorado Geological Survey. (Supply exhausted, but will be reissued as Bulletin 12.)

"Minerals and Rocks, the Elements of Mineralogy and Lithology for the Use of Students in General Geology" by W. S. Bayley: D. Appleton and Company, New York.

Mention may be made of a small body of granite near the head of McIntyre Gulch, which differs in composition from the ordinary granite but whose boundary was not traced. This is quartz-poor hornblende-biotite granite or quartz syenite which may have been separately intruded, or may be a facies of the common granite.

BIOTITE GRANITE (COMMON TYPES)

It may be that all varieties of biotite granite represented on the accompanying map by one pattern were intruded at practically the same time as different facies of one magma. But it is likewise possible that they were intruded successively through a period of long duration. In so far as can be determined from observed field relations all are younger than the pre-Cambrian schists and at least part of the quartzite, and may be younger than all the pre-Cambrian quartzite; they are older than the Upper Cambrian sediments. While it is not impossible that part of the granite was intruded in early Cambrian time, it is probable that nearly or quite all the granite of the region is of pre-Cambrian age.

Description.—The granite that is perhaps most often seen in the region and which might be considered a type, is a highly quartzose rock of medium to coarse grain. It is commonly even grained and massive or only slightly gneissoid, but locally gneissic structure is so pronounced that the name granite gneiss is applicable. It is usually gray of various shades, or reddish, weathering to dirty gray or reddish-gray. In some of the deeper mine workings, notably the Carter tunnel, much of the rock is pure white, excepting a sprinkling of black mica. Near the southeast corner of the mapped area and also near the head of Comanche Gulch and westward, the granite is commonly reddish.

Porphyritic granite is common in the west and northwest part of the area mapped. This is texturally of two kinds without observed intergradations. The first, which is ordinarily reddish and contains very little biotite, is often seen west of Comanche Gulch and northward several miles. At least half this rock is made up of feldspar phenocrysts whose average diameter does not exceed one-fourth inch. Many crystals are twinned according to the Carlsbad law. The groundmass is made up chiefly of small but megascopically determinable grains of feldspar and quartz. The second kind of porphyritic granite is found on and near Henry Mountain. Many of the feldspar phenocrysts of this granite have a cross-section of one-half inch by two inches each. Carlsbad twinning is common. Large grains of quartz, feldspar, and biotite make up the groundmass. Locally the rock carries quartz phenocrysts nearly half an inch in diameter, as well as large feldspar phenocrysts.

Near the source of Gold Creek and on the slopes of Fairview Mountain much of the granite has a pronounced gneissic structure.

The mineral composition of most of the granite of this region is simple. The minerals that can ordinarily be seen in hand specimens of the unaltered rock are feldspar, quartz, and biotite. The feldspar, variable in color, is commonly white, gray, or red. Carlsbad twins are frequently seen in the potash feldspar. Rarely albite twin striations on the cleavage faces of plagioclase may be seen under a lens. Quartz is abundant; it is generally in small grains though locally individual grains may have a diameter of half an inch. Biotite varies greatly in quantity, ranging from perhaps 10 per cent of the rock mass to a negligible component. In general, it forms a very small percentage of the rock. This mineral is commonly in aggregates of little flakes which, in specimens taken from near the surface, show more or less alteration. Of the observed alteration products chlorite is probably the most common, yet muscovite is not infrequently seen.

Thin sections of the granite contain apatite, zircon, titanite, black iron ore, biotite, feldspar, quartz, and secondary muscovite, chlorite, epidote, kaolin, limonite, and a carbonate which is probably siderite. Not all of these are present in every thin section examined.

Apatite, in minute stout crystals, is extremely rare. Small zircon crystals were observed in only one slide. Titanite is commonly absent; but one slide contains plentiful accessory titanite in small formless grains, while a second slide carries a few euhedrons and anhedrons of the same mineral. Euhedrons and subhedrons of magnetite, very probably pyrogenetic, are found in a few thin sections of fresh rock. Formless grains of black iron ore—ilmenite or magnetite—may be seen in several specimens of rock that shows alteration of the biotite; this ore is probably secondary.

Biotite or its alteration products may be seen in all the thin sections examined. It is the common brown variety in flakes that have a considerable range in size. Alteration to chlorite and muscovite is very common; these two minerals are closely associated in some specimens. Less abundant derivatives are black iron ore, hematite, limonite, and epidote. A carbonate, probably siderite, is occasionally seen.

The **feldspar**, which makes up perhaps nearly two-thirds of the rock, is dominantly potash feldspar. Both orthoclase and microcline are abundant. With them is microperthitically intergrown, in several specimens, subordinate plagioclase, probably albite. Much of the rock contains a small amount of independently crystallized plagioclase whose extinction angles, birefringence, refractive index as compared with that of quartz, and apparent absence of Carlsbad twinning strongly indicate albite. The feldspars show more or less alteration to kaolin and sericite.

Quartz is abundant in this granite and composes perhaps not less than 30 per cent of the average rock. It sometimes is micrographically intergrown with feldspar. While the quartz of a few specimens shows no evidence of strain, undulatory extinction is generally pronounced in this mineral.

A few specimens, notably those from the Cortland mine and the Roosevelt tunnel, show that the granite has locally been subjected to shearing stresses that either fissured or partly crushed the rock. Evidence of the former is found in the veinlets of quartz and a carbonate that cross the thin sections. Crushing is indicated by the narrow bands of finely-granulated material that alternate with bands of unfractured minerals.

Fine-grained granite.—The biotite granite area represented on the map by one pattern, contains irregular patches and dikes of finer-grained rock that ranges in composition from alaskite to biotite granite with granodioritic affinities, and in texture from even-grained granite to granite porphyry. These varieties are gray to red in color and massive to slightly gneissoid in structure. They probably represent facies of the magma from which the more common granite crystallized.

About half a mile west of the mouth of Boulder Creek is a small stock of nearly typical alaskite. The rock is composed essentially of quartz, orthoclase, and microcline, and is fine grained, even-granular, and gneissoid.

Much of the alaskite of other parts of the district contains a few phenocrysts of quartz and albite in a fine-grained groundmass composed mainly of orthoclase, plagioclase, and quartz. The groundmass carries also many flakes of muscovite besides a little hematite and limonite. These three minerals have probably been derived from biotite.

Less alkalic varieties contain considerable biotite and sodic andesine. One specimen carries phenocrysts of andesine in a comparatively coarse microgranitic to micrographic groundmass which contains, in addition to quartz and feldspar, much biotite and accessory magnetite, zircon, and apatite.

BRONCHO MOUNTAIN GRANITE

A comparatively small body of granite unlike the ordinary kind is exposed on Broncho Mountain about half a mile southeast of the top. Since this rock differs materially in composition, texture, and color from the rest of the granite of the district it has been separately mapped, and for purposes of reference is here called *Broncho Mountain granite.*

The mass is stocklike in surface outline, but appears to be older than the surrounding granite. Evidence of this was noted at the contact between the two kinds where the common variety is pegmatitic near the border and sends out at least one dike into the Broncho Mountain granite. The dike, which is 4 to 6 feet wide, can be traced at least 100 feet between walls of the Broncho Mountain granite. The latter rock was therefore sufficiently solidified to fissure before the intrusion of the pegmatitic granite which is evidently a facies of the common granite.

Description.—The granite here considered is commonly reddish, but facies very rich in biotite are almost black. The rock is medium grained and massive to strongly gneissic. Biotite is everywhere plentiful and locally composes about half the rock mass. Owing to the abundant biotite the rock is commonly tough and breaks with difficulty under the hammer. In both massive and gneissic varieties the mica flakes are commonly bent, though there may be no appreciable parallelism in their orientation in the massive rock. These conditions indicate a kneading of the rock mass while in a viscous state subsequent to the crystallization of biotite.

Red feldspar is so abundant as to give a reddish color to the rock. The feldspar grains have a maximum diameter of five or six millimeters but are commonly small. The quartz in the rock is dark gray and can easily be distinguished from the feldspar in hand specimens. It varies greatly in quantity from place to place. Locally quartz is so scarce that the rock approaches syenite in composition.

The pyrogenetic minerals seen in thin sections are zircon, apatite, biotite, orthoclase, microcline, microperthite, microcline-microperthite, and quartz. Magnetite, limonite, and muscovite are present in small quantity as secondary minerals.

Zircon is rare and in minute crystals. Apatite is a plentiful accessory in crystals and formless grains which can be seen with the aid of the low powers of the microscope.

In addition to the biotite flakes seen megascopically, there are multitudes of minute flakes of the same mineral which can be seen only under the microscope. The majority of the biotite flakes, both megascopic and microscopic, have been bent by pressure and movement. Some shreds appear to have been torn from the larger flakes after crystallizing. Not a little of the biotite shows alteration to muscovite by the evident leaching out of iron, resulting in the formation of magnetite and limonite in minute grains and patches.

The **feldspar**, in so far as observed, is entirely alkalic and principally potassic. Orthoclase and microcline are present in nearly equal quantity, and frequently grade into each other in the same grain. Albite is microperthitically intergrown with both potash feldspars.

In the thin sections examined **quartz** forms perhaps between 20 and 30 per cent of the volume of the rock. Nearly every grain shows undulatory extinction. Both quartz and feldspar show numerous fractures. The stressed character so apparent in the several minerals may have been imposed on the rock at the time of the intrusion of the ordinary granite.

PEGMATITE

Pegmatite occurs near the border of the granite in several places in the north and west parts of the area mapped. It forms dikes, a few inches to many feet wide, as well as irregularly-shaped masses that reach several hundred feet across.

In texture the pegmatite ranges from that of coarse granite to one in which individual masses of quartz and feldspar have a diameter of several feet, the feldspar locally showing crystal forms.

As is usual with pegmatite the composition varies greatly, though the bulk of the rock is made up of quartz and potash feldspar. In places there is, in addition to the minerals named, considerable biotite or muscovite. In other places black tourmaline is abundant. There was found, about a mile south of Carbonate Camp, a crystal of beryl which evidently had been weathered out of the pegmatite.

QUARTZ MONZONITE

Several dikes of dark-colored, granular rock cut the granite near the head of Jones Gulch, and are sometimes found crossing the metal-bearing veins. The rock is fine grained, even-granular, massive, and dark gray. It is commonly dioritic in appearance.

One specimen taken from the dump of the Grand Prize mine was examined microscopically. This seems to be a typical quartz monzonite, having nearly equal amounts of orthoclase and plagioclase, a considerable quantity of quartz, much hornblende, and a little biotite. A small amount of magnetite is present as an accessory.

QUARTZ DIORITE

Several small stocks of quartz diorite are found in the northwest part of the mapped area. Where this rock was observed in contact with the granite the grain is much finer than that of the quartz diorite at a distance from the contact. A few narrow dikes of the quartz diorite—evidently apophyses—were observed cutting the granite. These phenomena indicate that the quartz diorite is intrusive in the granite. Locally, narrow pegmatite dikes cut both granite and quartz diorite near the border of the stock.

In general the quartz diorite is dark gray, massive, and even-granular, with medium grain. Nearly half the rock mass is made up of hornblende and biotite which can easily be distinguished from each other by the unaided eye. With these minerals are occasional cubes of pyrite. Gray to white feldspar, with subordinate quartz in small grains, composes about half the rock. For the most part the feldspar has a dull luster, but a few grains show twin striations on cleavage faces.

Thin sections of the quartz diorite contain apatite, zircon, titanite, magnetite, pyrite, hornblende, biotite, plagioclase, orthoclase, and quartz, besides secondary kaolin, calcite, epidote, and probably zoisite.

Apatite is present as needle-like crystals and stout prismatic crystals in considerable quantity. Zircon, in minute crystals, is rare. Titanite, in wedge-shaped euhedrons and anhedrons, is a plentiful accessory. Considerable magnetite in octahedrons and formless grains, inclosed by hornblende and biotite, is evidently a pyrogenetic mineral. Small cubes of pyrite are rare.

Of the essential dark minerals, **hornblende** exceeds biotite in most specimens examined. It is the common green variety, and almost entirely without crystal outline. A few individual grains have a diameter of about a centimeter, but most of the hornblende is in aggregates of small grains. The **biotite** is the common greenish-brown variety. It is in small flakes and in the main closely associated with the hornblende.

The **feldspar** is chiefly plagioclase in roughly tabular subhedrons. Many are twinned after both Carlsbad and albite laws, while a few combine albite, pericline, and Carlsbad twinning. Determinations by the Michel-Lévy method proved the plagioclase to be chiefly andesine varying from about $Ab_1 An_1$ at the center of the grain to a more sodic variety at the margin. Kaolin, epidote, and probably zoisite are common alteration products. Calcite is present, though less abundant than the other secondary minerals.

A small quantity of **orthoclase** and a greater quantity of **quartz** crystallized subsequent to the crystallization of the other essential components. The quartz, which shows slight undulatory extinction, forms perhaps 5 to 10 per cent of the rock mass.

BIOTITE SYENITE

Specimens of typical biotite syenite were collected at the top of Fairview Mountain at the east border of the area mapped. On the northwest shoulder of the mountain the country rock is granite up to within one-fourth mile, or less, of the peak. Whether the syenite is a facies of the granite mass or whether it was separately intruded, was not determined.

The syenite is medium grained and slightly gneissoid. The essential constituents are white feldspar and lustrous black mica. Most of the grains of feldspar and mica are between 1 and 4 millimeters in diameter. Under a lens many small, yellowish-green grains of epidote forming sharp boundaries with the feldspar, can be seen. Hand specimens also show a few well formed crystals of yellowish-brown titanite that have a maximum length of about 3 millimeters.

Under the microscope, titanite, magnetite, biotite, feldspar, quartz, and the secondary minerals, epidote, chlorite, muscovite, and kaolin, can be seen.

Titanite is present in formless grains and euhedrons. Magnetite occurs in subhedrons and euhedrons, some of which have a diameter of nearly a millimeter.

Biotite forms perhaps less than 10 per cent of the rock. It is the common variety and for the most part unusually fresh. A few flakes, however, show slight chloritization, while the small amount of muscovite present has probably been derived from biotite. It is also probable that the iron of the epidote was derived mainly from the biotite.

The **feldspar,** by far the most important component, is mainly orthoclase. An appreciable amount of microcline, in small grains, is present. Both varieties of potash feldspar show considerable kaolinization. A specifically undetermined plagioclase is present in considerable quantity. The moderately high birefringence is suggestive of albite rather than calcic species, yet the abundant epidote may have derived its lime content from soda-lime feldspar. This plagioclase also shows considerable kaolinization.

The **quartz** content of this syenite is practically negligible. Only a very few small grains were seen.

Epidote is abundant in crystalline aggregates, in formless grains associated with feldspar and with biotite, and in euhedrons surrounded by orthoclase.

HORNBLENDE-BIOTITE SYENITE

Several closely related rocks that may have crystallized from facies of the granitic magma are exposed over a considerable area between Comanche and Willow creeks. The surrounding normal granite appears to pass by gradations into a quartz-poor granite, thence into quartz-bearing syenite, monzonite, and diorite. Since well defined contacts are wanting, the boundary of the area in which these rocks are exposed can be indicated only approximately on the geologic map.

Probably the bulk of the rock within this area is quartz-bearing hornblende-biotite syenite, though there are monzonitic and dioritic facies. It did not seem practicable to represent the several kinds individually on the map; but the description of one, a somewhat extraordinary quartz-bearing pyroxene monzonite, is reserved for a separate section.

Description.—All the rock described here contains a considerable quantity of hornblende, and nearly every specimen collected carries quartz. However, the amount of quartz is small, and in many specimens can be detected only in thin sections under the microscope.

The composition, texture, and color vary not a little from place to place. In all the specimens examined feldspar is the most abundant mineral. It varies from light gray or reddish-gray to very dark bluish-gray. While the microscope shows that both potash feldspar and soda-lime feldspar are invariably present they cannot ordinarily be distinguished with certainty in hand specimens. The presence of plagioclase is evident, however, in that twin striations can frequently be seen, by the aid of a lens, on cleavage faces. Both hornblende and biotite in variable proportions are found in practically every specimen. Where quartz can be detected it is ordinarily in small grains and in small quantity.

The rock as a whole ranges in color from light gray to dark bluish-gray, but for the most part it is dark owing to the high content of hornblende and biotite. In texture the several kinds are even grained, ranging from medium to coarse. Locally black or brown biotite, in flakes up to an inch in diameter, poikilitically incloses or is intergrown with other minerals.

Apatite, black iron ore, titanite, hornblende, biotite, soda-lime feldspar, potash feldspar, and quartz are all determinable in nearly every thin section examined. One slide contains a fairly large grain of a strongly pleochroic mineral, probably allanite.

For an accessory component apatite is unusually abundant. It forms comparatively large crystals which have a maximum observed length of .6 mm. Black iron ore is a plentiful accessory in some specimens where it forms perhaps 5 per cent of the rock. Other specimens carry very little iron ore. In general the ore is in formless grains surrounded by or closely associated with titanite. Titanite is very common in small anhedrons and as a rim surrounding the iron-ore grains.

Hornblende and **biotite** together form probably between 20 and 40 per cent of the rock mass. The proportion of the combined amounts of these minerals varies greatly in different specimens as does the ratio between the two. In some specimens the two minerals are approximately equal in quantity, in others hornblende exceeds biotite many times. Hornblende is the common green variety. It not uncommonly incloses crystals of apatite and grains of determinable iron ore; but a few specimens show a great number of minute, opaque, dark inclusions which may or may not be iron ore. Biotite is partly in large flakes that inclose other minerals, but it is mostly in small flakes. It is mainly the dark green variety with a tinge of brown, though in a few slides the biotite is lighter brown and approaches, in appearance, that of the pyroxene monzonite described in the following section.

Soda-lime feldspar is greatly subordinate to potash feldspar in most specimens examined. It is subhedral to anhedral in form, and is sometimes inclosed by biotite and by potash feldspar. As approximately determined by measurement of extinction angles and as inferred from the appearance of Carlsbad twins in the 45-degree position between crossed nicols, this feldspar is sodic andesine.

Microcline and **orthoclase** are both present in several specimens, but microcline on the whole greatly exceeds the orthoclase. Taken together these two minerals form the most abundant constituent of the rock. There is, however, within the area here considered, a small amount of quartz diorite in which the potash feldspar forms only a small fraction of the total feldspar content. A few specimens of quartz-bearing monzonite contain potash feldspar and soda-lime feldspar in nearly equal amounts.

Quartz, though present in nearly every slide examined, perhaps does not form over 5 per cent of the rock on an average. In some specimens it is practically negligible. This mineral occurs as small interstitial grains and as intergrowths with orthoclase and microcline.

PYROXENE MONZONITE

Quartz-bearing pyroxene monzonite, in a body of undetermined extent, is closely associated with hornblende-biotite monzonite and hornblende-biotite syenite between Comanche and Willow creeks. In the field, before a microscopic examination had been made, the essential difference between the pyroxene monzonite and the other rocks named was not recognized; therefore they are not individually represented on the map. Furthermore, the character of collected specimens indicates that there are intergradations which would make difficult accurate placing of the boundary of the pyroxene monzonite.

Description.—In color the monzonite is very dark bluish-gray, almost bluish-black. It is even-granular in texture with medium to coarse grain, and is massive in structure. A striking feature of the appearance and composition of the rock is the presence of dark brown biotite which is intergrown with, and poikilitically incloses other minerals, and whose cleavage faces generally range from one-fourth inch to one inch in diameter. Several biotite individuals may be seen on the surface of each hand specimen. The biotite, which is distinctly brown, is the only component which shows an appreciable difference in color, on casual examination, from the average color of the monzonite. Other minerals that can be seen in hand specimens are feldspar, hornblende, and pyroxene. The last two are black, and cannot be megascopically distinguished from each other. The feldspar is dark bluish-gray to almost black; twinning striae can sometimes be seen, with the aid of a lens, on cleavage faces.

Under the microscope apatite, black iron ore, pyroxene, hornblende, biotite, plagioclase, orthoclase, and quartz are determinable.

Apatite is a plentiful accessory constituent, and forms larger crystals than it ordinarily does in igneous rocks. The largest crystals observed are about 1 mm. long by .5 mm. thick.

For an accessory component black iron ore is also plentiful. It occurs partly as formless grains and partly as individuals with well defined outline. It is possible that the latter replace some previously existent mineral. Many of the euhedrons and anhedrons, where not inclosed by hornblende or pyroxene, are surrounded by a fringe of finely flaked biotite. Others are embedded in or inclosed by a single grain of biotite. At least part of the ore is ilmenite or titaniferous magnetite, since material removed with a magnet from the rock powder reacts for titanium.

Pyroxene forms at least 15 per cent of the thin sections examined. Much of it is dark, dirty gray owing to abundant inclusions that resemble magnetite powder. Inclusions of determinable black iron ore are common. In sections about .03 mm. thick, as determined from the interference color of quartz, the pyroxene reaches greenish-yellow to yellowish-green between crossed nicols, and therefore has a birefringence of about .028 to .029. The extinction angle is nearly 45°. Pleochroism is pronounced: Y = violet-brown; X and Z = very pale green, almost colorless. The optical properties indicate diopside with a considerable iron content. The mineral probably approximates, in composition, the variety known as salite or common pyroxene. The pyroxene has crystallized in euhedrons, subhedrons, and anhedrons. One rather large twinned individual cut parallel to the pinacoid (010) is bounded on each side by the trace of prism or orthopinacoid. Basal parting is conspicuous at each edge, but excepting occasional minute patches, enters the crystal a very short distance. At the edges the parting planes are fairly regularly spaced throughout the length of the crystal. Small patches that show basal parting may be seen at the interior of other grains.

Some diopside grains show intergrown hornblende or biotite. Instances of the three minerals intergrown may be observed. Not a few diopside grains are surrounded by a narrow fringe of biotite. Between this fringe and the surrounded diopside there is commonly a narrow band of finely divided black iron ore.

Hornblende is greatly subordinate to the diopside. It is brownish-green in color and extinguishes at about 20°. Its intergrowth with pyroxene and biotite has been mentioned. A few grains are surrounded by a narrow border of biotite. Not uncommonly the hornblende carries inclusions of determinable black iron ore; and, like the diopside, many grains are dark, dirty gray owing to the abundance of minute, dark, opaque inclusions.

Biotite exceeds hornblende in quantity, but is subordinate to the pyroxene. It is light brown or yellowish-brown and somewhat resembles phlogopite in appearance. Basal sections give a distinct biaxial interference figure, but the optic axial angle is small. The crystallization period of the biotite appears to have been unusually long. It variably forms intergrowths with pyroxene and hornblende; poikilitically incloses apatite, iron ore, pyroxene, and plagioclase; surrounds iron ore, pyroxene, and hornblende as a fringe; and is micrographically intergrown with quartz as one of the latest products of crystallization. In the last named occurrence the volume relations between biotite and quartz are apparently the same as the volume relations between orthoclase and quartz where these two minerals are micrographically intergrown. In several instances the quartz passes in optical continuity from a feldspar-quartz intergrowth to a biotite-quartz intergrowth without apparent change in relative volume.

Plagioclase is approximately equal to orthoclase in amount. It generally forms subhedrons of fairly large size which crystallized prior to the biotite. It is dark gray from the presence of numerous inclusions which appear to be similar to those of the pyroxene. While the quartz and orthoclase likewise carry similar inclusions they are so much less in these minerals than in the plagioclase as to make possible the determination of the approximate boundary of the plagioclase grains in transmitted light without the aid of the upper nicol. Measurements according to the Michel-Lévy method show that the plagioclase is labradorite having a composition of approximately $Ab_9 An_{10}$. It is fairly uniform in composition from core to border of the individual grains.

Orthoclase and **quartz** are generally micrographically intergrown in this rock, and both carry minute opaque inclusions. The intergrowth of quartz and biotite has been mentioned. A few independently formed quartz grains are present.

DIORITE AND RELATED ROCKS

In the central and southern parts of the mapped area are many irregularly shaped stocks and wide dikes of dark hornblendic rocks which are represented on the map by one pattern. These rocks are mainly diorite, though a few small bodies of basic syenite and monzonite are present. Several smaller bodies of hornblendic intrusive rock are not shown on the map. Furthermore, it is nearly or quite impossible to distinguish between certain varieties of hornblende gneiss and gneissoid diorite in the field, and it is possible that a few areas included with the gneiss on the map might better be classed with the diorites.

In a separate section there was given a description of typical quartz diorite which is found in the northern part of the district, is uniform in composition, and easily distinguished from the quartz-bearing diorite included here.

Field relations indicate that diorite was intruded at intervals through a long period. Much of it is massive and shows no evidence of dynamometamorphism. Some of it is structurally similar to varieties of the regionally metamorphosed rocks, and was probably intruded previous to the final stage of metamorphism.

The age relations between the diorite and the granite have not been determined with certainty. It is probable that at least part of the gneissoid diorite is older than the granite, while the massive diorite may be partly or wholly younger than the granite.

Description.—Many textural varieties of diorite are present, but it is perhaps impossible to select any one as a dominant type. In general, however, the rock is fairly uniform in character throughout the exposure of any single body, yet two not widely separated masses may differ greatly in textural features.

The diorite is nearly all dark gray to grayish-black where fresh. Weathered surfaces are commonly greenish-gray or reddish. Most of the rock contains a large proportion of hornblende which generally ranges perhaps from 50 to 80 per cent of the rock. The rock is hence unusually high in hornblende for a diorite, and the most basic phases might correctly be called hornblendite.

Hornblende, biotite, and feldspar are the only minerals that can ordinarily be determined megascopically.

The hornblende grains commonly range from one-sixteenth to three-eighths of an inch in diameter, but in one variety of diorite they sink to almost microscopic dimensions. This mineral is usually without crystal outline in the rock here considered, but in one exposure south of Quartz Creek the bulk of the rock is made up of equidimensional hornblende grains, one-eighth to three-eighths of an inch in diameter, which strongly resemble phenocrysts of a porphyry.

Usually very little biotite can be seen in hand specimens, but one variety of diorite contains many biotite flakes half an inch, or more, across.

Feldspar as a rule is inconspicuous. In much of the rock it is uniformly distributed. In one variety of diorite the feldspar is in phenocryst-like individuals. Another kind shows equidimensional patches of aggregated small feldspar grains. A third variety, composed mainly of coarse-grained hornblende, carries numerous minute, chainlike aggregates of small feldspar grains which are conspicuous on weathered surfaces.

Under a microscope the following minerals are determinable: apatite, black iron ore, pyrite, titanite, hornblende, biotite, soda-lime feldspar, potash feldspar, and quartz. Epidote and sericite are present as alteration products in some specimens.

Apatite in minute grains is very rare. A small amount of black iron ore may be seen in many slides; it is probably in large part secondary. Small pyrite grains are present in several thin sections. Though absent from a number of specimens examined, titanite is generally present in formless grains. It very commonly surrounds or is closely associated with anhedral grains of black iron ore.

Hornblende is abundant in every specimen examined. It commonly forms more than half the rock mass, and locally exceeds all other components several times. It is the common green variety, and generally subhedral or anhedral in outline. In hand specimens of one variety of diorite found south of Quartz Creek the hornblende individuals look like well formed crystals, but the microscope discloses ragged borders.

Biotite is absent from most specimens, but in one variety of diorite this mica nearly equals the hornblende in amount. Here it is principally in large grains, though partly in small flakes as it occurs where a component of the other diorites of the district.

Feldspar in most of the diorite is subordinate to hornblende, and in some varieties probably does not exceed 15 per cent of the rock mass. In several specimens it is exclusively soda-lime feldspar, evidently andesine for the most part; though calcic labradorite was noted in one slide. Not infrequently orthoclase in small quantity accompanies the plagioclase. A few varieties contain potash feldspar in amount equal to or greatly in excess of soda-lime feldspar, and are therefore monzonitic or syenitic.

Quartz is generally absent or present in very small quantity. It is usually accompanied by orthoclase with which, in rare instances, it is micrographically intergrown.

PORPHYRIES AND RELATED ROCKS

The dense porphyries and related rocks of this region are quantitatively unimportant. They occur in dikes and other minor intrusions having small exposed surface area. One of the largest bodies—that of granite porphyry somewhat monzonitic in composition—lies in the Quartz Creek mining district mainly outside of the area covered by the accompanying map.

The largest exposure within the mapped area is north of Carbonate Camp where erosion has uncovered a very thick sheet of andesite porphyry. A similar body is exposed about three-fourths of a mile north of Boulder Lake. North of the mouth of Hills Gulch a small stock—or possibly a chonolith—of rhyolite porphyry is crossed by Gold Creek. In addition to the occurrences mentioned are many dikes which are usually less than 50 feet wide.

The dense igneous rocks are of two general classes: (1) andesite porphyry and diorite porphyry; (2) quartz-bearing porphyries and related rocks. The second class includes rhyolite and rhyolite porphyry, granite porphyry, and a closely related rock called micro-granite in this bulletin.

AGE

The texture of the micrgranite indicates that it cooled more slowly than the other porphyries. Evidences of slight metamorphism are found in the same rock. It is therefore not improbable that the micrgranite was intruded under a much thicker cover than were the late intrusives and hence at an earlier period. Its intrusion was possibly prior to the period of erosion that preceded the deposition of Upper Cambrian sediments.

The other dense igneous rocks may have been intruded during a single period of vulcanism. In so far as can be determined they are younger than the youngest Paleozoic sediments of the region and are hence, at least in part, late Carboniferous or post-Carboniferous in age. Not unlikely they were intruded in Tertiary time.

ANDESITE PORPHYRY AND DIORITE PORPHYRY

The bulk of the rock mapped as andesite porphyry and diorite porphyry would probably be called by the former name by most petrographers. But the small body about a mile and a half southwestward from Henry Mountain, while almost identical in composition with the greater part of the rock here considered, is sufficiently coarse in texture to make the name *diorite porphyry* appropriate.

Description.—The andesite porphyry is nearly uniform in texture and mineral composition. White feldspar phenocrysts—mostly between one-sixteenth and one-fourth inch in diameter—constitute perhaps one-third to one-half the rock mass. Albite-twin striations can be seen on fresh cleavage faces. Black, prismatic hornblende crystals one-sixteenth to one-fourth inch long are abundant. Occasional yellow titanite crystals may be seen. The phenocrysts are embedded in a dense groundmass. The freshly broken rock is bluish- or greenish-gray, but weathered surfaces are commonly light gray.

All the feldspar phenocrysts that are determinable in thin section are plagioclase having the characteristic albite twinning, with which is combined pericline or Carlsbad twinning in some specimens. Zonal banding is common, but there is very little difference in composition between the center and border of the crystal. Extinction angles indicate that the plagioclase phenocrysts are mainly calcic andesine.

The **hornblende** is green to brownish-green and has an extinction angle of about 20°. Chloritization is very common. The chlorite is accompanied in some slides by calcite and magnetite.

Titanite is very irregularly distributed. Some slides carry many small crystals; others show no titanite.

The **groundmass,** while everywhere dense, differs somewhat in different specimens. It is generally micropoikilitic to common-microgranular, but an approach toward felty appearance is occasionally seen. Lath-shaped plagioclase microlites form the bulk of the groundmass in some specimens. But these are usually accompanied by a varying quantity of anhedral orthoclase grains. In the micropoikilitic groundmass the orthoclase grains inclose plagioclase microlites. Subordinate quartz in minute grains is present in the groundmass of a few thin sections.

MICROGRANITE

This seems to be the most suitable name for the rock of the dike that crosses Gold Creek at the mouth of Last Chance Gulch and of another dike west of the same creek but a short distance farther north. The rock is pink to gray in color. In texture it is intermediate between fine-grained granite and rhyolite. It carries small phenocrysts of quartz and feldspar, but the bulk of the rock is groundmass of fine-sugary texture whose granularity is scarcely evident to the unaided eye.

The microscope shows that the phenocrysts and also the microgranular groundmass include both orthoclase and microcline. The groundmass is much coarser in texture than that of the rhyolite porphyry described below, and is composed essentially of quartz, potash feldspar, and muscovite.

A slight directional structure, the presence of microcline, and the coarseness of texture—for dikes so narrow—point to the possibility that this rock was intruded in pre-Cambrian time, or at least long before the other porphyries.

GRANITE PORPHYRY

East of Islet Mountain, both within and without the area mapped, are several intrusions of quartz-bearing porphyry whose texture is almost that of typical granite porphyry. A similar rock is found in a dike in Hills Gulch.

Phenocrysts of the porphyry are almost equal, in bulk, to the groundmass. White to pinkish feldspar is the most abundant phenocrystic mineral. The majority of the crystals are less than one-fourth inch in diameter, but a few have a diameter of three-fourths of an inch. The numerous quartz phenocrysts rarely exceed three-eighths of an inch across. Though not conspicuous, small biotite phenocrysts are plentiful. The microgranular groundmass is gray.

In thin section orthoclase is seen to be the principal feldspar, but several phenocrysts of plagioclase—andesine or a more sodic variety—are present. Kaolin and sericite are common alteration products. In a specimen from east of Islet Mountain many quartz crystals show the prism with rhombohedral terminations, but the quartz phenocrysts of the Hills Gulch rock are much corroded. Most of the biotite has been replaced by chlorite and a varying quantity of epidote and magnetite. The microgranitic groundmass is composed chiefly of quartz and orthoclase with a few lath-shaped plagioclase microlites.

RHYOLITE PORPHYRY AND RHYOLITE

The rhyolite porphyry has a greater proportion of groundmass and usually a finer-textured groundmass than has the granite porphyry described, while the two kinds of rock have essentially the same mineral composition. The supposed rhyolite porphyry includes several textural varieties which probably differ but slightly in chemical composition.

Most of the quartz-bearing porphyry is badly weathered and hence difficult to classify exactly. It is not impossible that part of the rock is latitic or dacitic in composition.

The most abundant variety of rhyolite porphyry forms a stock north of the mouth of Hills Gulch and a number of dikes east of Gold Creek. Among the dikes may be mentioned one cut by the Carter tunnel, one near the Volunteer mine, one or more in the vicinity of Cameltown, one on Islet Mountain, and two northwest of Fairview Mountain. The porphyry of the long dike in and near Boulder Fault is similar in composition but finer in texture.

The porphyry, both at the surface and in the mine workings, is generally greatly weathered. On fresh fracture it is white to greenish-gray to reddish or brownish, varying with the character of the alteration. Some weathered surfaces are black with a thin coating of oxide of manganese. Much of the surface rock is pitted owing to the removal of phenocrysts of feldspar—and probably biotite—by weathering. Specimens from the mines carry kaolin or kaolin-like pseudomorphs after feldspar.

Quartz is abundant in phenocrysts from one-sixteenth to one-half inch in diameter, and is the only primary mineral that can ordinarily be identified in hand specimens. Many phenocrysts show distinct crystal faces, while others are greatly corroded. Pyrite crystals are common in the porphyry of the mine workings. Moderately weathered porphyry of a dike near Fairview Mountain carries identifiable feldspar phenocrysts and chloritized biotite or chlorite pseudomorphs after biotite.

The only unaltered primary minerals seen under the microscope are quartz and zircon, the latter in minute quantity. Though kaolin—with a little sericite—has replaced much of the feldspar, considerable feldspar remains as grains in the groundmass and as phenocrysts. Most of this is evidently orthoclase, but a few phenocrysts of plagioclase are present in some specimens. The biotite crystals have been completely replaced, mainly by chlorite, epidote, iron oxide, and calcite. The micrograniti̇c groundmass is composed essentially of quartz and orthoclase.

The other varieties of rhyolite porphyry differ from the one described chiefly in carrying fewer and smaller phenocrysts.

Some of the dikes are nearly or quite non-porphyritic. Though they are in the main probably rhyolitic in composition, a few are too finely crystallized for exact determination without chemical analysis. Lacking analysis these supposed rhyolites might best be called by the non-committal name *felsite.*

CHAPTER V

PALEOZOIC AND QUATERNARY DEPOSITS[1]

BY P. G. WORCESTER.

Only five periods of the Paleozoic era are represented in this district, and all the younger rocks are of Quaternary age.

In order to simplify correlations as far as possible all of the Paleozoic rocks with the exception of those of the Pennsylvanian system have been compared with the corresponding sediments in the Crested Butte district.

In the case of the Pennsylvanian sediments it did not seem advisable (for reasons which are fully stated in the discussion of those rocks), to continue the name applied to them in the Crested Butte district. Instead of adopting a local name, which would simply add to the confusion of Pennsylvanian names already in use, the formation has been mapped under the symbol C, and the question of the proper name left open. When future work in Colorado has established more of the connecting links between the sediments of the central and the southern parts of the state, it will be an easy matter to name correctly the rocks of this district.

Very few good fossil-bearing horizons were found. It is possible that others were overlooked, but considerable time was spent in the search for fossils and the results were very unsatisfactory. In nearly every case where fossils were found they were poorly preserved, and the question of their determination has been a difficult one. If more and better material had been found, the subdivision of the sediments might have been different from the one that has been made. It is not likely, however, that such would have been the case, for, although many of the fossils were imperfect, enough specimens of each species were found to make the identification fairly reliable.

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[1]Dr. George H. Girty was kind enough to read the section on Paleozoic Deposits. His suggestions and criticisms are gratefully acknowledged.

CAMBRIAN SEDIMENTS

SAWATCH QUARTZITE

The oldest of the Paleozoic sediments in this area is a more or less metamorphosed sandstone formation, which is here provisionally called the Sawatch quartzite. It occurs on top of the ridge south of Quartz Creek opposite Ohio City, on Fossil Ridge, on the south side of Fairview Mountain, in and west of Chicago Park, and in many other small local areas.

Section of Cambrian sediments at Fossil Ridge

Top		Feet
4	White or pink sandstone, weathers gray or brown	28
3	Thin-bedded, clayey, more or less micaceous, cherty quartzite, locally red or green in color	49
2	Massive, white or gray, fine-grained quartzite	40
1	White, well rounded quartz conglomerate	2
		119

The formation consists of four well defined members.

At the base, lying on the uneven pre-Cambrian floor of gneiss or schist, there is usually a bed of conglomerate which is never more than 2 or 3 feet thick. Occasionally it is absent, but is generally present wherever the upper sandstones occur. The composition of the conglomerate is extremely variable. Near Lookout Mountain it is made up almost entirely of well rounded and well washed quartz, flint, jasper, and chert pebbles which range from one-eighth to one-fourth of an inch in diameter. At one place on Fossil Ridge the conglomerate consists of a few white quartz pebbles, ranging from 1 to 4 inches in diameter, with a matrix of white sugary quartz grains. In other places the grains are about one-sixteenth of an inch in diameter. The color is always white when the conglomerate is fresh, but it is usually brown when weathered.

The first rock above the conglomerate is a massive, fine-grained, compact white quartzite. It is a pronounced cliff maker and, as a rule, is the most prominent member of the formation. The lower 8 or 10 feet is somewhat friable, but it becomes harder with distance from the base. Although the color is generally white, it may be yellow, green, or red depending upon local impurities of clay or iron.

The third member of the formation is a thin-bedded quartzite, interlaid with several thin calcareous beds. The quartzite is generally fine grained, dense, and hard, but near the base an 8- or

10-inch stratum of coarse, red, micaceous quartzite is often present, while higher up there are many small lenses of compact green clay.

The upper member of the formation is a thick-bedded, saccharoidal sandstone which looks very much like the massive quartzite below. It is thinner bedded than the quartzite, however, and is more likely to be colored brown or red. The beds are from 2 to 4 feet thick, and the whole member is a decided cliff maker. The color, while variable, is usually white, but it may be pink, red, or brown, due to the amount and condition of the iron present. The prevailing composition is pure quartz sand with some iron oxide and a silica cement. Mica in small quantities sometimes occurs.

The thickness is quite variable. The beds apparently were deposited upon a very uneven pre-Cambrian floor, and in consequence they vary from 30 to 140 feet in thickness.

AGE

No unconformity could be found between the various members of the formation and none was found between the upper sandstone and the basal Ordovician limestone.

In the thin-bedded quartzite on Fossil Ridge there are suggestions of fossils, but nothing was found that could be identified. On the projection of Fossil Ridge, east of Comanche Gulch, in the same thin-bedded quartzite one specifically unidentifiable trilobite was found. Since no other fossils were found, it is evident that there is no fossil evidence to support the view that these rocks are of Cambrian age, and it becomes necessary to fall back on a comparison of the stratigraphic position and lithological character of these rocks with those of the Sawatch quartzite in neighboring areas, whose age has been more definitely determined.[1]

In the Anthracite and Crested Butte folio, Eldridge describes the Sawatch quartzite as follows:

> This formation, so named because of its persistent occurrence around the flanks of the Sawatch range, is the lowest sedimentary series in the region and is of upper Cambrian age. It is extremely variable in thickness, and is separable into a lower and an upper division, each of which forms prominent cliffs.
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> The lower division, which is from 50 to 200 feet thick, is a pure white quartzite with a persistent conglomerate at the base. The upper division,

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[1]Emmons, S. F., Geology of the Leadville District, Colorado: U. S. Geol. Survey Mon. 12, p. 58.

Spurr, J. E., Geology of the Aspen Mining District, Colorado: U. S. Geol. Survey Mon. 31, p. 4 (1898).

Emmons. S. F., U. S. Geol. Survey Geol. Atlas Ten Mile District, Colorado, folio No. 48, 1898.

Eldridge, G. H., U. S. Geol. Survey Geol. Atlas Anthracite and Crested Butte folio No. 9, 1894.

which has a maximum thickness of 150 feet, is a red, ferruginous and somewhat calcareous sandstone, consisting chiefly of quartz and feldspar, with a small amount of mica. A green, glauconitic mineral occurs in both divisions, but more abundantly in the upper. In the latter a few fossils of the Potsdam type were found.

Emmons, in the Ten Mile folio, gives this description:

> This formation is made up of a series of remarkably pure white, evenly bedded quartzites, with a fine-grained conglomerate at the base. In the upper part the beds contain more impurities and pass into reddish and greenish argillaceous and calcareous shales, in which have been found fossils belonging to a Dikellocephalus fauna of upper Cambrian age. * * * The thickness averages 160 to 200 feet.

These descriptions agree so well with the beds in question that it has seemed best to use the name Sawatch quartzite for this formation. It is possible, however, that too much has been included in this formation. Eldridge, in the Anthracite and Crested Butte folio, described, as the basal member of his Yule limestone, a quartzite which immediately overlies the Sawatch quartzite of that area. His description is as follows:

> The lower quartzite, 75 to 100 feet thick, is generally white, sometimes spotted by iron oxide, often calcareous, and contains indistinct fossil remains.

This horizon may be included in the Sawatch quartzite of the Gold Brick area. It certainly is included if it occurs there at all. But no well defined stratigraphic break occurs anywhere within the formation and no other evidence was found to indicate that part of the beds were of Cambrian and part of Ordovician age. Hence the age of the whole formation is regarded as upper Cambrian.

ORDOVICIAN SEDIMENTS

YULE LIMESTONE

The Ordovician sediments are well exposed in nearly every part of the area where sedimentary rocks younger than the Cambrian are found. Typical exposures are on Fossil Ridge and around Boulder Lake. There the headwaters of the streams have worn down the alternating hard and soft layers in the great natural amphitheatres and good opportunities are offered for the detailed study of the rocks.

Section of Ordovician sediments at Fossil Ridge

Top	*Upper non-fossiliferous member*	Feet
7	White, cream, or mottled red and green, fine-grained, compact, somewhat sandy, dolomitic limestones, alternating with thin beds of sandy, green shale	27
6	Mottled red, green, or chocolate, sandy shales with thin beds of light colored limestones	18

		Feet	
5	Brownish-gray, arenaceous shales and shaly limestones, thin bedded, somewhat ripple marked	11	
4	Brown, coarse, even-grained quartzite	1	
			57
	2 Lower fossiliferous member		
3	Massive blue limestone, dolomitic, sandy	35	
2	Quartzite, white, or red due to iron stains; many impressions that look like pieces of wood or fish scales, but may be inorganic; 10-inch green shale parting in the center	8	
1	Thin-bedded limestone, sandy and clayey; gray or light blue with local green or red tints; very cherty at base; less cherty near top	196	
			239
	Total		296

The section gives the average characteristics of the rocks referred to this system, but there are many variations that should be noted. The reasons for dividing the system into a lower and an upper member are discussed under Age.

LOWER MEMBER

The basal limestone varies greatly in thickness. On Fossil Ridge, where the section given above was measured, the thickness is 196 feet, while on Fairview Mountain near the Fairview mine it is 290 feet. The color, while predominately steel gray at the base and distinctly blue in the upper third of the horizon, may at any place be green, red, or purple, particularly on weathered surfaces.

Near the base of the limestone large quantities of gray or black chert occur as nodules or elongated lenses between the bedding planes, or more often within an individual stratum. Much less chert is found at the middle and very little at the top. Sand and clay are also much more abundant near the base, while the limestone becomes distinctly dolomitic in the upper part.

At the base the beds range from 3 inches to 3 feet in thickness, but most of them average less than 1 foot. In the upper part of the horizon the beds are much thicker and form prominent cliffs in many places.

In the lower strata the limestone is crystalline and porous. In the upper beds it is fine grained and compact. Locally, east of Fossil Ridge, it has been changed to marble through contact metamorphism.

Above the basal limestone there is a very persistent stratum of quartzite with an equally persistent 8- or 10-inch green shale parting. The thickness of the whole varies from 6 to 15 feet. The texture varies from medium to fine grained. There are a great many small iron concretions present, and the color, which is originally white, may be a dull brick red or brown due to the leaching of the iron. There are many very peculiar markings in the quartzite associated with the iron concretions, which strongly suggest fossils, but Professor Junius Henderson has been unable to find any organic remains and they are regarded as peculiar phases in the structure of the concretionary forms.

Similar quartzites were found on Monarch Hill by R. D. Crawford in 1910, and this horizon is believed to be the same as number nine of the Ordovician section of the Monarch and Tomichi districts.[1]

This quartzite in the Gold Brick district is locally called parting quartzite, but it is apparently lower stratigraphically than the so-called "Parting Quartzite" of the Leadville district, and it is not believed that there is any relationship between the two.

Above the quartzite there is another limestone horizon which varies greatly in thickness. On Fairview Mountain it is 65 feet thick. Near Pitkin it is 47 feet, while at the section at Fossil Ridge the thickness is only 35 feet.

The color is blue-gray or dark blue. It is massive, dolomitic, and may or may not contain chert. It usually contains more or less sand and clay, particularly in the upper strata. Since it is a cliff maker and since it contains a great many fossils, this limestone is a prominent horizon marker.

UPPER MEMBER

A one-foot stratum of light gray, coarse quartzite which weathers brown is usually, but not always, present at the base of this horizon. It marks the transition from the massive fossiliferous limestone of known Ordovician age to the Fairview shales and the succeeding non-fossiliferous shale limestone series whose age has not been determined.

Fairview shale is the local name applied to a thin-bedded, often ripple marked series of calcareous, sandy shales and sandy, shaly limestones, which constitute the hanging wall in the Fairview mine. The color is a dull gray or brown. The composition is very variable although the beds themselves are persistent. The thickness varies from 10 to 15 feet.

[1]Crawford, R. D., Geology and Ore Deposits of the Monarch and Tomichi Districts, Colorado: Colorado Geological Survey Bulletin 4, p. 57, 1913.

Above the Fairview shale there is a series of green, dark red or chocolate-colored shales, with limestones and an occasional band of fine-grained, compact quartzite of the same color. A detailed vertical section in one place would vary greatly from another section a short distance away. The shales give way laterally to limestones, and vice versa. The whole series represents an easily recognized horizon which can be followed throughout the area.

The limestones are usually dolomitic, light green or cream colored, with green, red, or purple tints. They weather to a peculiar yellow color because of which they are called locally "Buckskin limestones." Often the texture is that of a good lithographic limestone. As a rule the individual beds of limestone or shale are less than 2 feet in thickness, but they sometimes reach 6 or 7 feet.

AGE

The following fossils were obtained from the lower fossiliferous member.

The basal limestone Number 1 in the section yielded:

Dalmanella Cf. testudinaria (Dalmen)?
Dalmanella hamburgensis Walcott
Reticularia sp. (?)
Lingula sp. (?)

The second limestone horizon, No. 3 of the section, yielded:

Halysites catenulatus
Receptaculites oweni
Platystrophia (?) sp.
Heliolites (?) sp.
Undetermined Corals, Brachiopods, Gastropods, and Fish Scales.

The invertebrate fossils named above as well as all others found in the younger rocks were identified by Professor Junius Henderson.

Fish scales were found in a somewhat sandy phase of the limestone (No. 3 of the section) at the top of the horizon.

Professor T. D. A. Cockerell examined these fossils and his report follows. For a more detailed statement see The American Naturalist.[1]

Also compare Professor Henderson's statement of the stratigraphic importance of these fragmentary fish remains.[2]

Professor Cockerell says:

The scanty fish remains found in the Paleozoic rocks at Ohio City, regarded by themselves, would appear to indicate a Devonian fauna.

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[1]Cockerell, T. D. A., Ordovician (?) Fish Remains in Colorado: The American Naturalist, vol. 47, April, 1915.

[2]Henderson, Junius, Recent Progress in Colorado Paleontology and Stratigraphy. Proc. Colo. Sci. Soc., vol. XI, pp. 11-12, 1914.

(1) A fragment of a plate exhibiting fine grooves with deep pits, resembling, so far as it goes, the plate of *Coccosteus disjectus* from the Old Red Sandstone, figured by A. S. Woodward (Cat. Fossil Fishes, Brit. Mus., Part 11, Pl. VIII, fig. 1). The structure is also nearly identicai with that of *Astraspis dcsiderata*, as figured by Walcott, from the Ordovician of Canon City. (Bull. Geol. Soc. Amer., vol. 3, 1891, Pl. 3, fig. 7.) Some of the other figures of Astraspis might well belong to Coccostean fishes.

(2) A large fragment, having a diameter of over 30 mm., is covered with irregular, obtuse vermiform ridges, and is *exactly* like the opercular plate of *Rhizodus ornatus* (Woodward, t. c., Pl. XII, fig. 5), so far as sculpture goes. This particular species is Lower Carboniferous, but Rhizodontid fishes also occur in Devonian.

(3) Numerous fragments of striated spines, some short, conical and straight, others more slender and curved, appear to exactly correspond, so far as they go, with the spines of *Diplacanthus*, from the Lower Old Red Sandstone. One of the supposedly Coccosteoid plates, 5 mm. thick, with the surface finely striate, with punctate more or less branching striae or grooves, occurs in the same piece of rock as a supposed *Diplacanthus* spine, the two almost touching.

According to the evidence available, we seem therefore to have three families of fishes represented: (I) Coccosteidae; (2) Rhizodontidae; (3) Diplacanthidae. The genera and species cannot be precisely determined.

From the number and variety of fishes of these types occurring in the Devonian, it is evident that they have had an early origin, so that they may be expected in the older rocks. Walcott's Ordovician species were said by Professor James Hall to have such a Devonian facies that he would certainly have referred them to the Devonian, but for the accompanying invertebrate fauna. It must, therefore, be said of the remains now under discussion that, while they appear to be Devonian, it is by no means impossible that they are older.

In considering this statement by Professor Cockerell, attention must be called to the fact that these fish remains are too imperfect to be of much value in stratigraphic determination.

Since these fish remains were found in a horizon which contained such typical Ordovician fossils, and since the first Devonian fossils, disregarding the fish remains, were found nearly 100 feet above the horizon, it seems evident that this horizon should be regarded as of Ordovician age. This horizon seems to correspond with the middle division of the Yule limestone of the Crested Butte quadrangle which Girty[1] regards as Ordovician.

No fossils were found in the Fairview shales and in the succeeding variegated shale and limestone horizons, mapped OY (?) and included provisionally here in the upper Ordovician. These

[1]Girty, G. H., Carboniferous formations and faunas of Colorado: U. S. Geol. Survey, Prof. Paper 16, p. 155, 1903.

rocks are apparently what Eldridge[1] included in his upper division. of Yule limestone.

Spurr[2] correlates the Upper Yule limestone of the Crested Butte quadrangle with the Parting quartzite of the Aspen district and the Parting quartzite of the Leadville district.

Girty[3] discusses the evidence of the age of Eldridge's upper Yule limestone, Spurr's Parting quartzite, etc., and his conclusions are quoted as follows:

> While positive proof is lacking, it seems to me that a number of circumstances favor the correlation of these shales in the Crested Butte district and San Juan region. * * * Its correlation with the Aspen section and position in the time scale, however, are questions apart, and I am indisposed to accept the evidence for the Devonian age of this horizon as conclusive.

On page 161 of the same report Girty says:

> Although Spurr found Devonian fishes in the Parting quartzite of Aspen, it should be borne in mind that similar fish remains of Devonian types occur in the Harding sandstone, whose Ordovician age seems to be secure, and in the calcareous division of the Yule limestone in the Crested Butte quadrangle, of whose Ordovician age there is little doubt.
>
> In view of these facts the force of this evidence is largely destroyed. Considering that the only known Paleozoic horizon in Colorado distinguished for its fish remains is in the Ordovician, that the Parting quartzite is separated from the Leadville limestone, at Leadville at least, by an erosional unconformity, and that the lower portion of the Leadville limestone contains over large areas a Devonian fauna, it seems to me that the evidence preponderates in favor of the Ordovician rather than the Devonian age of the Parting quartzite.

In view of the existing uncertainty with regard to the age of this horizon it has seemed best to provisionally include it with the Ordovician, but to show it on the map by a different pattern, which will allow readjustment should the age later be proved to be Devonian.

DEVONIAN-MISSISSIPPIAN SEDIMENTS

LEADVILLE LIMESTONE

A limestone formation containing Devonian fauna in the lower part and Mississippian fauna in the upper part is of widespread occurrence in the western half of the state. It was first described in the Leadville region, and was given the name Leadville limestone. This name was also used for the same formation in the Anthracite-

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

[2]Spurr, J. E., Geology of the Aspen mining district, Colorado: U. S. Geol. Survey Mon. 31, p. 20, 1898.

[3]Girty, G. H., U. S. Geol. Survey, Prof. Paper 16, pp. 156-161. 1903.

Crested Butte and Ten Mile districts. The geologists of the San Juan district gave the name Ouray limestone to a formation which they regarded as the Devonian portion of the Paleozoic section of the San Juan. A subsequent discovery of a Mississippian fauna in the upper portion of the limestone proved the practical identity of the Ouray and Leadville formations. On account of the priority of the name "Leadville limestone," the writer of the present chapter has adopted that name for the formation in the Gold Brick district. But since these names are used to denote rocks of the same age and especially to represent the undivided Devonian-Mississippian sediments of Colorado, it probably makes little difference which name is used here.

Considerable time was devoted to a systematic search for fossils in an attempt to separate these systems, and it is believed that this attempt was successful in the region about Fossil Ridge, but as it was not possible, because of the overburden, to divide them throughout the area, they are necessarily mapped together. Since it seems highly desirable to distinguish between the systems wherever possible, a tentative division is made in the following section which represents the average characteristics of the formations at Fossil Ridge. The evidence upon which this demarcation is based is discussed under *Age*.

Section of the Leadville limestone at Fossil Ridge

Top		Feet
	(a) Mississippian sediments at the head of Comanche Gulch.	
16	Dark blue limestone with black chert; one thin yellow porous bed near the top	20
15	Thin-bedded, brown or dark gray, very cherty limestone	17
14	White quartzite	1
13	Very dark blue, cherty limestone with nearly black limestone breccia	24
12	White, even-grained quartzite	16
11	Thin-bedded, blue, cherty limestone	74
10	Massive, blue, strongly magnesian limestone	50
9	Yellowish, porous, sandy, magnesian limestone	5
8	Thin-bedded, brown or gray, clayey and very cherty limestone	10
	(b) Devonian sediments near the head of Comanche Gulch.	
7	Massive, blue or brownish gray limestone	138
6	Blue or gray limestone; massive at the base, thin-bedded near the top. Locally may contain an intra-formational conglomerate	152
5	Thin-bedded, brown, clayey, magnesian limestone	25
4	Hard, compact, light-gray magnesian limestone	23
3	Blue, thin-bedded, cherty magnesian limestone with clayey limestones at the base	62

		Feet
2	Dark blue, nearly black, fossiliferous, magnesian limestone; massive at the base, thin-bedded, clayey and sandy near the top	25
1	Brown, fine-grained, slightly calcareous quartzite..............	12
		654

DEVONIAN SEDIMENTS

The Devonian sediments are made up almost entirely of limestones. Only one quartzite, No. 1 of the section, is persistent. Although no fossils were found in the quartzite, it is included with the Devonian because there is always a sharp break between it and the upper Yule shale-limestone series below, while it grades in some places almost imperceptibly into the strongly fossiliferous horizon above. In two or three exposures the "quartzite" was found to be really a sandstone, but as a rule it is a true quartzite. The thickness varies from 6 feet just west of Pitkin to 15 feet at one place on Fossil Ridge, but the average is about 12 feet.

The second member of the section, the dark blue limestone, is the most important fossil-bearing stratum in the formation. Above the lower 2 or 3 feet of rather coarse, sandy or clayey limestone, it is compact, fine grained, and extremely hard. Locally, about 10 feet above the base, the color may change to a dark gray or greenish gray due to the addition of clay. Fossils occur throughout the stratum.

From the top of the dark-colored, fossiliferous horizon to the top of the Devonian system there is a decided lack of uniformity in the composition of the rocks.. Four sections measured across the formation show a distinct lack of agreement, although the differences are relatively unimportant. The conditions of deposition seem to have been very different in closely associated areas, for the limestones, which are ordinarily pure, give way to conglomerates, sandstones, or shales, which may have a lateral extent of a few hundred feet or possibly 1 or 2 miles before they gradually grade back to limestones.

The thin-bedded, gray, cherty limestone, No. 3 of the section, is fairly continuous throughout the area. The chert occurs as small nodules and is not so abundant as it is in the Cambrian and Ordovician rocks.

The two next younger members of the formation are not always separable. Both are strongly magnesian, and both may or may not contain thin beds of clay or sandstone. The thin bedding, hardness, and compact texture are distinguishing features.

The limestones of horizon 6 are perhaps the most variable of all. In general the rock is a pure limestone; the basal beds are massive enough to make pronounced cliffs and the upper beds shelve back and form low terraces. Quartzites and sandstones may occur near the middle of the horizon, but they are not persistent. On Fairview Mountain a 10-foot stratum of quartzite occurs in such a position. West of Chicago Park this quartzite band is only 4 or 5 feet thick, while on Fossil Ridge it cannot be found at all, although there may be an occasional thin bed of conglomerate or shale in about the same position as the quartzite of Fairview Mountain. The quartzite is fine grained, rather dense, and usually weathers brown. The conglomerate is composed of small, well rounded pebbles of quartz, chert, and limestone.

The upper Devonian limestone is a pronounced cliff maker. Some of the beds are 40 or 50 feet thick, and cliffs 100 feet or more in height are common. The color is rather variable, but blue predominates when the limestone is pure. If clays or sandstones are present, the color is likely to be changed to some shade of green, brown, or yellow. The upper half of the horizon is strongly magnesian. Fossils abound, but are so poorly preserved that few could be identified.

MISSISSIPPIAN SEDIMENTS

There are only a very few exposures of these rocks in the Gold Brick district, and it is possible that the brief description which follows does not fully indicate the character of the sediments as a whole. The largest outcrops are in the amphitheatre at the head of Comanche Gulch and at the head of Alder Creek. Smaller areas are exposed in Chicago Park and on the south slope of Fairview Mountain.

There is a marked lithological break between the Devonian and the Mississippian sediments. The yellow or brown colors, the black chert that is invariably present, and the clayey or sandy character of the basal limestones make these beds good horizon markers and they offer sharp contrasts to the underlying massive, blue Devonian rocks. All the lower Mississippian beds are strongly magnesian, but above the 16-foot quartzite stratum little or no magnesium is found.

The quartzite is very persistent and is found wherever there are good exposures of the formation. It is generally pure white, even, rather fine grained, hard and very compact. It is almost always brown after it has become weathered.

Above the quartzite the beds are remarkable for their large chert content. The chert is dark gray, dark brown, or black. It often occurs in small nodules which show well defined bands of lighter colors. Sometimes the concretions are a foot or more in diameter and these larger masses are likely to be red or a light pearl gray color. Some fossil remnants are found in the chert concretions, but none could be identified. The 1-foot stratum of quartzite which was found at Fossil Ridge is not found in other parts of the area. It seems probable that the conditions of deposition were rather uniform during the period of formation of these rocks, for with few exceptions the beds are much alike wherever they are found.

AGE

The basal Devonian limestone yielded the following fossils:

Streptelasma or Zaphrentis
Crania (?) sp.
Schuchertella chemungensis (Conrad)
Camarotoechia endlichi (Meek)
Athyris coloradoensis Girty
Spirifer whitneyi Hall
Euomphalus cf. eurekensis Walcott
Undetermined Polyzoa and fish remains.

The upper member of the formation is not so well represented.

Fossils provisionally identified as *Zaphrentis sp.*, *Spirifer whitneyi*, *Euomphalus* cf. *eurekensis*, and many undetermined brachiopods, called by Professor Henderson "probably Devonian" were collected from this horizon. But all of these forms were poorly preserved and in his report on their identification Professor Henderson said: "The specimens from this horizon identified as *Euomphulus* cf. *eurekensis* and *Spirifer whitneyi* are very imperfect and might easily be Mississippian instead of Devonian." Since many of these fossils were found in this horizon in widely separated localities, and since they were all provisionally assigned to the Devonian age, it is assumed that the Devonian system ends with this horizon.

The basal limestone of the Mississippian yielded very few fossils. All were in poor condition and only one from the Fossil Ridge section, *Spiriferina solidirostris* White, was even provisionally identified. This specimen was incomplete, and Professor Henderson said: "Its identity is doubtful." However, Mr. Butters found the same form in beds at the head of Alder Creek, which he was able to correlate very definitely with the basal member of the Mississippian section at the head of Comanche Gulch, where the Fossil Ridge section was measured. The latter specimen is in good condition and there seems to be no doubt as to its identity. If this identification is correct, and if Mr. Butters' correlation of the horizons in the field, based on lithological grounds, is correct, it is believed that the contact between the Devonian and the Mississippian systems has been established.

A section was measured on Fairview Mountain, but because of the overburden of soil and mantle rock it could not be correlated in detail with the Fossil Ridge section. The Devonian rocks were well exposed, and the approximate limits of the Mississippian were defined. From the latter system the following fossils were obtained:

Syringopora aculeata Girty
Syringopora surcularia Girty
Spirifer sp.
Bellerophon sp.
Straparollus (?) sp.
Undetermined cup corals, columnar corals, spirifer, and gastropods.

At the top of the Mississippian system there is a pronounced erosional unconformity. Above it there is an abrupt change in the lithological character of the sediments, and Pennsylvanian fossils appear.

PENNSYLVANIAN SEDIMENTS

These sediments, which are mapped under the symbol C, are the youngest Paleozoic rocks in the district. The principal exposures are south of Fairview Mountain, east and north of Chicago Park, on the west end of the ridge between Boulder and Comanche creeks, and at the head of Alder Creek. The last named region affords the best opportunity for studying the formation. In the other regions the sediments are largely covered with soil and vegetation.

Section of Pennsylvanian sediments at Fossil Ridge

Top		Feet
4	Alternating beds of black limestone and shale. The upper 75 feet is nearly all limestone	208
3	Black calcareous shale with thin-bedded, dark-colored sandstone and limestone	70
2	Brown or gray, thin-bedded, soft, argillaceous sandstone	5
1	Coarse, mottled red and yellow, thin-bedded sandstone with much chert	15
	Total	298

The lower sandstone is quite variable in thickness in different localities. It is coarse, sometimes conglomeratic, frequently calcareous, and nearly always contains chert. The chert occurs as red, pink, green, or gray concretions of varying sizes from an inch or two to a foot or more in diameter. The sandstone is usually mottled red, pink, tan, or yellow and gray.

In some places the sandstone grades into red shale; in others it becomes exceedingly calcareous and even grades into limestone. North of the Carbonate King mine considerable hematite was found in red, sandy shale almost at the base of the formation.

The upper horizons cannot be described in detail, for they are not sufficiently well exposed. In general they consist of black shale beds, from 6 inches to 1 foot in thickness, alternating with layers of black or very dark blue limestone, which may reach a maximum thickness of 6 feet. The shales are calcareous and the limestones are generally argillaceous. Black chert occurs sparingly in the middle and abundantly in the upper part of the horizon. Thin-bedded, brown sandstones occur in the lower half of No. 3, but their extent could not be determined because of the thick coating of mantle rock.

Fossils are found occasionally in the chert concretions of the basal sandstone. They are much more numerous in the upper horizons, but as a rule they are too poorly preserved to be identified.

AGE

These sediments are of the same general character as those of the Weber formation of the Crested Butte district. They occupy the same relative position unconformably on the Leadville limestone, their fossils are of Pennsylvanian age, and their rocks, which consist of shales, limestones, shaly limestones and sandstones, seem to be very much alike in composition and arrangement.

All of the older sediments have been correlated more or less definitely with those of the Crested Butte district and their names have been adopted, but it seems unwise to continue this practice to the extent of using the name "Weber" in connection with the formation under discussion. Girty[1] questions the propriety of the use of the term Weber for the lowest Pennsylvanian sediments in the Crested Butte district and shows that the name was long preoccupied by the Weber quartzite of the Wasatch range, which probably corresponds more closely to the Maroon of that district

[1]Girty, G. H., U. S. Geol. Survey Prof. Paper 16, 1913, p. 210.

than to the Weber formation. Rather than perpetuate a term which may have been mis-used, it seems best to avoid the use of the word "Weber" in this connection.

Girty[1] says: "The lower part of the Hermosa (and the Molas where present), which succeeds the Ouray, I am disposed to correlate with the Weber shale and the Weber limestone, which follow the Leadville limestone."

If the Weber of the Crested Butte district and the Pennsylvanian of the Gold Brick district are the same formation, the fossil evidence of the latter supports Girty's view. It was impossible to specifically identify a number of the specimens because of their poor state of preservation, but in so far as they are determinable, all, with the exception of *Marginifera haydenensis* Girty and *Orthonychia cf. acutirostre,* are duplicated in either the Molas or the Hermosa of Colorado.

The following fossils, all of which are Pennsylvanian types, were found in this district:

Crania sp.
Orthotichia schuchertensis Girty (?)
Chonetes sp.
Productus nebraskensis Owen (?)
Productus cora D'Orbigny
Productus sp.
Marginifera haydenensis Girty
Spirifer boonensis Swallow (?)
Squamularia perplexa (McChesney)
Composita subtilita Hall (?)
Bellerophon sp.
Orthonychia cf. acutirostre (Hall).

In composition the Pennsylvanian rocks of the Gold Brick district do not correspond closely to the Hermosa and the Molas of the San Juan region, but this is not surprising when the distance between the two districts is considered. The Hermosa of the latter district is more sandy and less calcareous than is the Pennsylvanian at Fossil Ridge.

Like the San Juan Molas the basal sandstone varies greatly in thickness because it lies on the uneven surface of the Leadville limestone which was elevated and deeply eroded before the Pennsylvanian sediments were deposited. The red and yellow colors, and especially the great number of chert concretions, also indicate a strong resemblance between the two formations.

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[1]Girty, G. H., Loc. Cit., p. 212.

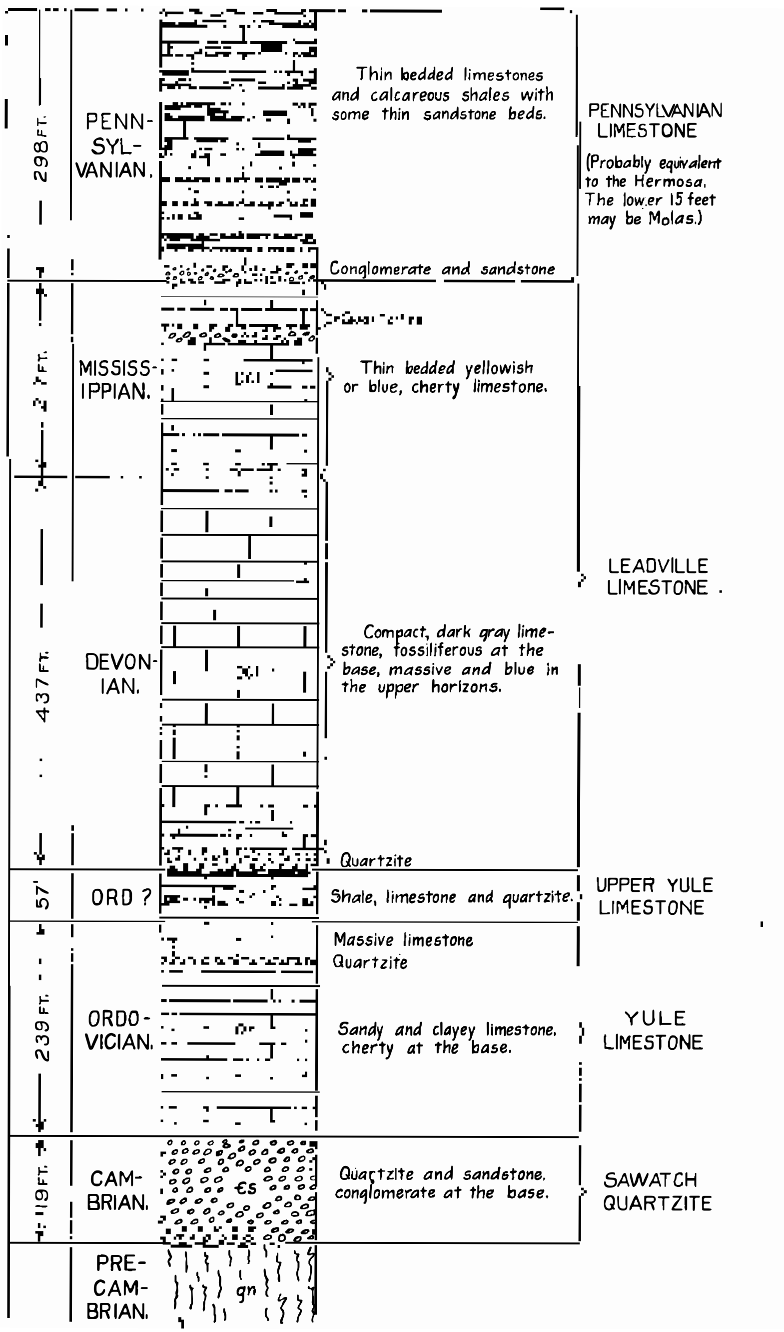


Figure 2.—Vertical section of the Paleozoic sediments of Fossil Ridge

Since comparatively little work has been done on the correlation of the Pennsylvanian sediments in the Crested Butte. Leadville, Aspen, Ten Mile, and neighboring districts, with those of the San Juan region, the question of correlation is left open in this report and the horizon is simply mapped as Pennsylvanian, although the fossil content and position of the beds indicate that they are equivalent to the Molas and the lower Hermosa.

QUATERNARY DEPOSITS

These deposits consist of moraines, probably of Pleistocene age, and alluvium which is in part derived from old moraines and in part is of recent origin.

MORAINES

Morainal material either in well defined moraines or more or less re-worked by streams, is found in all the valleys west of Fossil Ridge, in Comanche Gulch, in the Lamphier Lake region, along Gold Creek north of the Gold Links mine, and north of Fairview Mountain.

The best defined moraines occur west of Fossil Ridge and west of Gold Creek north of its junction with Lamphier Creek. In the latter locality moraines cover the end of a ridge 600 feet above the level of the creek bottom. The material was carried only a short distance, and its glacial characteristics are very marked. Huge striated boulders and rock flour are intimately associated. Angularity of outline is the characteristic feature of all the debris.

It is interesting to note that no moraines are found in the valley of Boulder Creek, which, in its upper part, is certainly a glaciated valley. Boulder Lake is a glacial lake, and the amphitheatre at the head of the valley is evidently a cirque. But, in this instance, the rocks eroded by the glacier were almost entirely limestones and shales which are easily disintegrated by weathering agents, and apparently the old moraines have been worn down and entirely carried away by the streams.

ALLUVIUM

Alluvium has been mapped all the way along Quartz Creek, along Willow Creek, in a few scattered areas west of Fossil Ridge, and practically the whole length of Gold Creek.

Quartz Creek is an overloaded stream, whose valley walls throughout most of its course are steep and barren. More debris is brought into the main valley by the tributary streams than can be carried away. The result is that the valley is filled up, and the creek meanders and deposits sediment over a rather wide flood plain.

Willow and Gold creeks are similar to Quartz Creek in that they too are overloaded, and the sediment brought in by the tributaries is not rapidly carried away by the main streams.

Most of the debris is fine-grained sand and gravel, although many good sized well waterworn boulders are found, especially toward the heads of the valleys.

ALLUVIAL FANS

Many alluvial fans and cones are found in the district. Nearly all the short, swift streams have built fans or cones at the foot of the slope where they empty into a larger valley. Fans are particularly noticeable along Gold Creek and on the south side of Quartz Creek.

CHAPTER VI

STRUCTURAL GEOLOGY

BY R. D. CRAWFORD

The principal structural features of this region which lend themselves to examination and which will be considered in this chapter are the results of regional metamorphism, folding, faulting, and igneous intrusion including attendant contact metamorphism. A few notes on the ore-bearing veins are given in the chapter on economic geology.

REGIONAL METAMORPHISM

The region surveyed contains numerous outcrops of ancient rocks whose sedimentary origin can be affirmed with much confidence, though a study of these rocks does not seem to disclose anything new that might aid in the explanation of dynamometamorphism. With these metamorphosed sediments are undoubted intrusives that apparently shared to a smaller degree in the regional metamorphism. Other greatly altered rocks of gneissic structure may have once been either igneous or sedimentary in so far as observed characters enable one to determine.

In pre-Cambrian time the then existent rocks were subjected to intense dynamic forces and were changed to gneisses, schists, and quartzites. The original bedding planes of the quartzite and also the planes of schistosity now strike northward throughout most of the district, and dip westward at a high angle or are nearly vertical. Among the minerals developed through metamorphism are amphiboles, andalusite, cordierite, garnets, micas, and pyroxene.

FOLDING AND FAULTING

In the region under consideration the attitude and relationships of the Paleozoic strata and such metamorphosed pre-Cambrian sediments as retain traces of their original bedding planes, furnish at the surface ordinarily the only means whereby the folds and faults may be worked out. Dislocation of the veins as disclosed by mine workings fix the positions of a few faults in the metamorphic and igneous pre-Cambrian rocks. To a slight extent physiographic phenomena may assist in working out the faulting. Since by far the greater part of the region is without recognizable sedimentary bedding as well as underground workings it is probable that only a small part of the folds and faults is represented on the geologic map.

The folds and faults are very probably only different expressions of the effect of the same or similar forces. In other words, the forces that produce the folding stressed the rock in places beyond the point of rupture and produced thrust faults, while the normal faults may mark the position of differential settling after the release of the stresses that caused the folding.

FOLDS

The rock structure affords proof that there have been at least two periods of folding. The first was prior to the deposition of the Sawatch quartzite and was in all probability in pre-Cambrian time. The second was subsequent to the deposition of all the Paleozoic sediments now present in the region, and was probably at the close of the Paleozoic era or later.

During the first general period which may have included several epochs of crustal disturbance, the rocks were subjected to an approximate east-west pressure which left the beds standing vertical or dipping at a high angle. These stresses may have been accompanied by the regional metamorphism or may have in part followed the metamorphism that was general throughout the mountain area of Colorado and neighboring states. Whether the metamorphic rocks within the area mapped were comprised within a few folds involving a great thickness of sediments or were part of a series of many anticlines and synclines involving less material, is indeterminable from the evidence at hand. Local variations of dip and strike of the schistosity suggest proximity to the ends of folds and hence several folds. These variations may have been brought about later by forces acting in different directions from those that produced the main folds. A third possibility is the disturbance of uniformity of dip and strike by igneous intrusions which were numerous in this region.

The Gold Brick district is a small part of a large region whose rocks were subjected to folding at the close of the Paleozoic era or later, when numerous anticlines and synclines were developed. The general trend of the axes of these folds in central Colorado is north to west of north. The inclination of the remaining Paleozoic strata in the area mapped indicates that the trend of the axes of the folds here corresponds in general to the trend of the axes of the major folds of the Sawatch Range.

The eastward dipping sediments between Fairview Mountain and Quartz Creek constitute part of a synclinal fold that extends throughout a large area in the Quartz Creek mining district. This syncline was probably once connected with the sediments of Fossil Ridge by an anticline which has since been mostly removed by erosion.

On and near Islet Mountain the folding is more varied than elsewhere in the district. A mile southeast of the mountain there is a strong dip northeastward. Half a mile southeast of the peak the beds are vertical. At the peak the strata are overturned and dip southwest at an angle of 55°. A similar overturn may be seen about three-fourths of a mile north. Three-fourths of a mile northwest of the mountain the beds dip westward and are roughly parallel to the slope of the hill. This explains the unusually wide exposure of the Sawatch quartzite in this vicinity. On and near Islet Mountain we therefore have the eastward and northeastward dipping limb of a syncline, in part overturned and in part continuous with the eastward dipping limb of an anticline of which but little remains.

The strata of Fossil Ridge and environs have in general the structure of a syncline whose limbs have been broken by faulting. The synclinal dip is interrupted by a small anticlinal fold near Boulder Lake. (See Pls. V, B and VI, A.)

The Sawatch quartzite of Lookout Mountain and west of this mountain generally dips gently toward the south, and is probably part of a synclinal fold lying mostly without the area covered by the map.

FAULTS

Both normal and thrust faults are found here, though the largest known faults are thrusts. It is highly probable that the igneous and metamorphic rocks have been dislocated along fault planes that remain undetected, since faulting in rocks of this character may easily escape notice.

BOULDER FAULT

This fault, which passes under Boulder Lake, can be traced almost continuously from Sheep Mountain to Carbonate Camp, a distance of more than three miles. It probably extends farther southwest where, owing to the similarity of rock on both sides of the line of faulting, it is practically impossible to determine whether or not there has been a displacement.

This is a thrust fault; the pre-Cambrian rocks on the southeast side have been brought up opposite the Paleozoic sediments on the northwest side. The fault dips southeast at an angle of 40° to 60° throughout the greater part of its course. The southeast dip is well shown by the relation of the fault to the topography. This feature is brought out on the accompanying geologic map where the fault line may be seen to bend southeast in the several valleys where erosion has exposed the fault at a lower—and hence farther southeast—position than it occupies at the top of the ridges between the valleys.

The amount of displacement is indeterminable where no sediments are found southeast of the fault. On the ridge east of Comanche Gulch, where the throw and dip are determinable within certain limits, the displacement is about 2,000 feet. On the same ridge a body of Sawatch quartzite has been brought up to the highest point on the fault. This is evidently a remnant of the Sawatch beds of the hanging-wall side, which must have formerly occupied a higher position than at present and which settled by normal faulting subsequent to the main thrust.

Another interesting phenomenon at this point is the closed overturned fold which involves strata of limestone and shale having a thickness of perhaps 75 to 100 feet. (See Pl. V, A.) The extreme apex of the fold is covered by talus, but the beds on the inner part of the fold to the thickness of 30 or 40 feet can be traced continuously around the bend.

Plate V, B shows the sediments abutting against the pre-Cambrian rocks at the fault west of Boulder Lake.

CORTLAND FAULT

This fault was encountered in No. 4 tunnel of the Cortland mine, and it can also be seen at the surface where it has been traced only a short distance. It strikes N. 35° W. and dips southwestward at an angle of 50° to 60°.

Underground the dislocation is marked by a single streak of gouge at one point, and at another place by parallel breaks in the schist throughout a zone about 10 feet wide, while at the breast of the tunnel the abundance of gouge bears evidence of considerable

A. BOULDER FAULT NORTHEAST OF COMANCHE CREEK

B. BOULDER FAULT AND BOULDER LAKE LOOKING WEST shearing movement. The main fault intersects the principal ore-bearing vein of this tunnel at an acute angle. The amount of displacement of the vein has not been determined. For 25 feet, or more, along the course of the vein the original fissure-filling is brecciated; pyrite has been deposited subsequent to the brecciation. Furthermore, a small cross-fault containing breccia meets the main vein on the west side, but does not appear on the east side of the vein—that is, the small cross-fault is itself dislocated by a fault following the main vein. The last-mentioned movement may have been the one that caused the brecciation of the vein material or it may have preceded the primary mineral deposition. At any rate, we have in this short tunnel evidence of at least two periods of faulting separated by an interval of mineral deposition.

GOLD LINKS FAULT

About 1,500 feet north of the Gold Links tunnel a drift on the principal vein, which here strikes N. 35° E., encountered a fault or a zone of faulting which had cut off the ore. In trying to recover the vein toward the east and north the miners found much gouge and broken ground, but it is impossible to determine from relationships here the strike, hade, or direction and amount of throw of the fault. There are indications of several fault planes. Unfortunately the character of the country rock and the poverty in exposures make impossible, from surface indications, a certain determination of the strike of the fault.

Physiographic features suggest the possibility of a northward strike of the fault across the saddles of the three ridges between Browns Gulch and Dutch Flat Gulch. Not only has much material been removed by erosion along this course, but the dumps from several deep shafts show, by the character of the rock, that disintegration has reached an unusual depth in places as compared with the depth of disintegration on either side of the supposed line of faulting. But no conclusive evidence has been found that these depressions mark the trend of the fault. On the contrary, the felsite dike that crosses this line north of Hills Gulch seems to have suffered no displacement or even a break. It is not improbable, however, that the dike was intruded subsequent to the faulting.

An examination of the Gold Links tunnel where timbering was required to hold the heavy ground, between 3,000 and 3,200 feet from the portal and hence under one of the saddles noted above, strengthened the writer's suspicion that the fault passed through this vicinity. The rock here, as described by Mr. A. E. Reynolds and by miners who helped to drive the tunnel, is broken and disintegrated similar to the rock near the breast of the north drift where the fault was certainly encountered. The available underground evidence and the physiographic evidence both favor the position for the fault that is indicated on the map by dashes.

The Gold Links vein and the Sacramento vein are probably one and the same, though interrupted by faulting. The vein has a similar strike and dip in the two mines. The average strike of the vein in each of the two mines is N. 25° to 35° E. The dip is westward. An old Sacramento mine map, drawn to a scale not stated, shows that the vein dips westward at an angle not far from 45°. In the Gold Links mine, between the tunnel level and the 85-foot level below at the north end of the drift, the average westward dip is about 50°. In the absence of an accurate large-scale map combining the plans of the two mines and the absence of accurate determination of the vertical distance between the workings of the two mines, it is impossible to state the distance that the vein is offset on the tunnel level of the Gold Links mine. If the vertical distance between the Gold Links tunnel and the lowest level of the Sacramento is about 400 feet as the accompanying topographic map indicates, a cross-section would show the vein of the two mines in nearly the same plane, assuming the dip to be 45° or 50°. In other words, if the topographic map is correct there is probably a comparatively small offset in the vein at the level of the Gold Links tunnel. The northward extension of the vein is probably offset a short distance toward the east, but a slight westward throw seems possible.

OTHER FAULTS

Three faults found on the ridge east of Lamphier Creek are represented on the geologic map and in the section AA′. Special mention should be made of one because of the peculiar relationships of the faulted rocks. About three-eighths of a mile east of Lower Lamphier Lake is a mass of granite bordered by Paleozoic sediments on the greater part of three sides. On the northwest these beds abut against granite along a fault plane that strikes northeast. One gets the impression in traversing the ridge that the sediments which fringe the mass of the granite southeast of the fault mentioned underlie this granite. The granite has evidently been brought to its present position by faulting, since the limestone is not metamorphosed as it would necessarily be if the granite were an igneous intrusion in the sediments. The granite was probably forced into its present position by a thrust along the nearly horizontal bedding plane traced in section AA′. A possible alternative would be a thrust upward of a plug of granite, having more or less nearly vertical walls. There is, however, no observed field evidence for this alternative.

Several faults of considerable displacement were observed in the sedimentary areas near the east border and also near the west border of the district. They are represented on the geologic map.

Faulting of the Volunteer vein in the Carter mine has caused the owners of the mine much trouble, but details of these faults are not at hand.

A fault striking about N. 85° W. and dipping southward has been followed 200 feet by a drift in the Gray Eagle mine. Much gouge has been developed by the faulting, and striae on the slickensided walls indicate that there has been movement in three directions. In the same mine there is evidence of a southward-striking fault following the vein and subsequent to the deposition of ore.

IGNEOUS INTRUSION

Intrusive bodies that occur entirely or partly within the area mapped, include (1) batholiths, (2) stocks, (3) dikes, and (4) intrusive sheets. There are also intergradations, while certain intrusions, specified below, do not conform strictly to types.

BATHOLITHS

The essential difference between a batholith and a stock is one of size, and some geologists might designate as stocks all the bodies that are here placed in the first two classes named above. Daly,[1] basing a distinction on general usage, would "confine the term batholith to those subjacent masses which, at the outcrop, cover more than 100 square kilometers or about 40 square miles; a stock is of smaller outcrop area."

The granite of the west part and also that of the east part of the Gold Brick district belong to bodies of large extent. Though their boundaries have not been traced beyond the borders of the mapped area, it is probable that these bodies are much larger than those ordinarily called stocks. It is not known whether this batholithic granite was intruded in a single period of vulcanism or whether it includes masses intruded at widely separated intervals.

[1]Daly, R. A., Igneous rocks and their origin, 1914, p. 90.

In general the granite bodies have nearly vertical walls, and are intrusive in the oldest metamorphic rocks, namely, gneisses, schists, and quartzites. There is no observed evidence that the intrusions materially disturbed the older rocks in their position or attitude. A notable exception to the usual nearly vertical walls of the granite masses may be seen in the vicinity of Henry Mountain where the contact between the granite and the older schist is far from vertical. It is probable that there is here part of the former roof of the batholith, the greater part of the roof having been removed by erosion.

STOCKS

Several comparatively small bodies of granite and of diorite and related rocks are typical stocks. They have nearly vertical walls and their plans are irregular in outline. Many of the dioritic stocks, having long and narrow outcrops, approach dikes in form. In fact, there are a number of bodies that might be called either dikes or stocks.

The body of quartz-bearing porphyry north of the mouth of Hills Gulch differs from a typical stock in the slope of its walls. Typical stocks commonly have either nearly vertical walls or walls sloping outward with increasing depth; the stocks are thus likely to enlarge downward. In a drift along the east border of the porphyry mentioned, on the lowest level of the Bellzora-Bassick mine, the porphyry-gneiss contact dips westward at an angle of 65° to 72°, nearly corresponding to the dip of foliation of the gneiss. The attitude of the west wall of the intrusion is not determinable from surface indications. If this wall is vertical, or dips eastward symmetrically to the east wall, the porphyry mass has the shape of an inverted cone and is somewhat chonolithic in form. But the west wall may dip westward, and, if so, the porphyry forms a westward-dipping stock. The direction of the intrusion may have been influenced by the structure of the inclosing gneiss and schist whose planes of foliation dip westward at a high angle.

DIKES

Besides the diorite bodies that are more or less stocklike, there are many that are typical dikes, of which the largest are shown on the geologic map. Many small diorite dikes and stocks, intrusive in the gneiss and schist, were not separately mapped. The diorite dikes commonly trend northwestward or northward, and in places follow the strike of the foliation of the inclosing metamorphic rocks. They have a much greater average width than the porphyry and felsite dikes of later age. The longest diorite dike observed in this region has been traced about 5 miles from near the mouth of Jones Gulch to a point southeast of Quartz Creek, where it passes beyond the border of the area mapped. This dike has a width varying between 200 and 1,000 feet, with an average of perhaps 700 to 800 feet.

The felsite and porphyry dikes are mainly of later age, and cut both pre-Cambrian and Paleozoic rocks. A dike that crosscuts Paleozoic strata may bend and follow the bedding for a considerable distance as an intrusive sheet or sill. (See Pl. VI, B.) Most of the dikes of late age are comparatively narrow; but few have a width of 50 feet. One of the widest outcrops a short distance west of the Volunteer mine, where a northward-trending dike swells locally to a width of perhaps 500 to 700 feet.

INTRUSIVE SHEETS

In general the andesite porphyry seems to be intrusive in or below the Paleozoic sediments in sheetlike form, rather than as crosscutting dikes. The intrusion shown in Plate VI, B can be traced 2½ miles. For half the distance, or more, it lies between the Sawatch quartzite and underlying pre-Cambrian rocks as an interformational sheet. Near each end of the exposure it crosscuts the quartzite and follows a higher horizon for a considerable distance as a sill.

Near the head of Comanche Creek is one of the largest exposures of andesite porphyry of the district. Exposed contacts follow the bedding planes of the sediments in places, and this body is hence in part sheetlike.

The bodies of andesite porphyry mentioned are disconnected by but short intervals at the surface. It is not improbable that these and others are connected at a depth not very great, if indeed they were not fed to their present position through a single channel. All have evidently been greatly reduced by erosion, and it is impossible to determine the relative thickness and horizontal extent of the original bodies. They were, in all probability not typical laccoliths, yet they have some features suggestive of laccoliths.

East of Islet Mountain are several intrusions of quartz-bearing porphyry whose structural relation to the surrounding sedimentary rocks has not been fully determined. These bodies are perhaps, for the most part, intrusive sheets.

CONTACT METAMORPHISM

Regional metamorphism of the oldest pre-Cambrian rocks is so general and pronounced that possible metamorphic effects of the pre-Cambrian intrusions are not conspicuous. The post-Paleozoic porphyry intrusions did not cause appreciable contact metamorphism of the pre-Cambrian rocks, but the sediments of Fossil Ridge are slightly metamorphosed, in places, at and near their contact with the andesite porphyry.

The metamorphism most commonly takes the form of crystallization of the limestone. Fine-grained marble is found at a number of places on both sides of the ridge above the head of Comanche Creek and about a mile north of Boulder Lake. Pronounced metamorphism as a rule extends only a few feet from the contact; but at one place, about two miles north of Carbonate Camp, marble is found more than 100 feet from the andesite porphyry outcrop.

Nearly a mile north of Boulder Lake the andesite magma flowed through a fissure in the cherty limestone, and spread out laterally as a sill between overlying strata. (See Pl. VI, B.) The limestone is crystallized and the chert itself is completely replaced by or altered to silicate throughout a zone that extends many feet from the contact. The material occupying the position of the former chert nodules is greenish-gray, soft, and compact; it is evidently a mixture of serpentine and talc. These minerals have in all probability been derived from diopside or other non-aluminous silicate which in turn was formed through metamorphism attending the porphyry intrusion. The writer has described[1] a somewhat similar occurrence in the Monarch mining district where diopside after chert is only partly altered to serpentine.

Several prospect holes have been sunk on the porphyry-limestone contact near the head of Comanche Creek north of Carbonate Camp. Though no metamorphism other than crystallization of limestone was noticed beyond a few feet from the contact. considerable iron ore—chiefly magnetite and limonite—has been deposited at the very contact. Near Carbonate Camp a few hundred feet from the outcropping andesite porphyry, red iron ore—probably turgite—has been taken from a shallow prospect hole.

Garnet is found on a prospect dump at the porphyry-limestone contact near the head of Comanche Creek. The mineral is yellowish-brown to dark brown and massive. It is in part associated with

[1]Colo. Geol. Surv. Bull. 4, 1913, p. 112.

A. FAULT, FOLD, AND AMPHITHEATER WEST AND NORTHWEST OF BOULDER LAKE

B. PORPHYRY INTRUSION IN GRANITE AND OVERLYING SEDIMENTS ONE MILE NORTH OF BOULDER LAKE coarsely crystallized calcite. Chemical tests show that the garnet is andradite in which a small amount of magnesium replaces calcium and a small amount of aluminum replaces ferric iron.

CHAPTER VII

ECONOMIC GEOLOGY

BY R. D. CRAWFORD

GROUND WATER

The depth of the permanent ground-water level in this region is unknown to the writer. During the summer water stands in many of the abandoned shafts only a short distance below the surface. It is stated that in former years when the snow was thawing water ran over the collar of the Cortland shaft when the pumps were not running.

The three long tunnels driven eastward from Gold Creek have drained many of the old mine workings and have furnished channels for much water that formerly would have run down the gulches to Gold Creek. Very little water now flows in Hills, Dutch Flat, Spring, and Jones gulches. However, there is still a good spring at Cameltown.

GEOLOGICAL RELATIONSHIPS OF ORE BODIES

The accessible mine workings afford only limited opportunities for detailed study of the ore bodies, but the bulk of the ores are determined to be of the fissure-vein type. Subordinate replacement deposits and contact deposits are known.

FISSURE-VEIN DEPOSITS

Though the ores are mainly fissure-vein deposits, the veins have evidently been materially widened in places by replacement of the wall rock. This is true of veins both in the regional-metamorphic rocks and in the granite. The amount of widening of the veins by replacement is unknown, but it is probably not less than a foot to a foot and a half on each side of the vein in many places. Locally there is a sharp boundary between ore and wall rock, but more commonly the ore shades, by gradually decreasing metallic content, into the country rock. Crustification has been noted in the Gold Links vein.

In the metamorphic rocks quartz schist, containing some sericite or talc, commonly forms one wall of the vein, and not infrequently carries pyrite or limonite. Lenticular masses of pegmatite, usually less than 3 feet thick, are sometimes seen in contact with or very near the ores, and may themselves carry a small amount of gold. Both in the veins and at the border of the veins in the granite are commonly found patches of decomposed mica schist or highly micaceous gneissic granite. A similar rock, but fresher, is found in a wide lead cut by the Carter tunnel where lenses and apparently discontinuous veins of quartz up to 3 or 4 feet thick are separated by patches of what is probably a quartz-poor and biotite-rich granite.

Besides the metallic minerals and residual patches of country rock the vein-filling is chiefly massive quartz in many places. In other places, notably in the veins in the gneiss and schist, much gouge is found.

In general the ore is not continuous in the veins in a horizontal direction, but is in shoots whose vertical extent has not yet been determined. Some of the smaller bodies might be called bunches or pockets.

OTHER TYPES OF ORE BODIES

The ore of the Bellzora-Bassick mine, at the contact between quartz-bearing porphyry and regional-metamorphic rocks, is evidently a typical contact deposit. At and near the porphyry-limestone contact near Carbonate Camp and near the head of Comanche Creek are small deposits of iron ore of the contact-metamorphic type. The ore is mainly magnetite though some hydrated ferric oxide of unknown derivation is present. The limestone near the ore has been changed to marble, and in one place garnet has been formed. The replacement zinc ores of the Carbonate King probably owe their origin to the intrusive andesite porphyry of this region.

A small amount of galena replacing limestone has been found near Boulder Fault not far east of Comanche Creek. The ore of the Silver Islet mine was in all probability a replacement deposit.

RELATION OF ORE DEPOSITS TO FAULTING

The gouge seen in several veins in the metamorphic rocks suggests the probability of faulting prior to ore deposition and the possibility that the fissures of the fissure veins were caused by faulting. The occurrence of uncrushed metallic sulphides with fault breccia in the Cortland mine proves beyond a doubt that there has been mineral deposition subsequent to faulting, but the sulphides here may be of a period long subsequent to the period of primary deposition.

Though it is probable that there was some faulting prior to the period of original ore deposition there has been pronounced faulting subsequent to this period. This is proved by the big fault that interrupted the Gold Links vein, and also by the smaller faults that dislocated the Volunteer vein of the Carter mine. These faults were probably formed at about the same time as the several faults that have been traced in the limestone. These latter faults, though they pass through easily replaced limestone, do not appear to have been the channels for any considerable quantity of metal-bearing solutions. There is no known extensive mineralization of the limestone along these faults, though small amounts of zinc, lead, and iron occur in and near the Boulder fault between Boulder Lake and Comanche Creek.

GENERAL CHARACTER OF THE ORES

Although considerable lead has been produced by the mines of this district the chief values of the ores are in their gold and silver content. Copper, molybdenum, and zinc occur here, but have not hitherto been found in paying quantities. Gold and silver vary greatly in amount and also in their ratio to each other—here one, there the other greatly dominates in value. The ore is likely to be spotted: very lean ore may give way within a few feet to ore that carries several ounces gold or about 100 ounces silver per ton. The rich and poor ore may be almost identical in appearance.

The values of the bulk of the ore formerly produced were carried by limonitic quartz, and few of the mines seem to have produced much sulphide ore. Within the oxidized ore bodies was found residual galena carrying good values in gold. Much of the Cortland output has been sulphide ore. In this mine sulphides are found within 40 feet of the surface. The Chronicle mine also probably produced sulphides.

Though the Gold Links and Raymond mines have produced considerable sulphide ore from their deepest workings, neither has reached a depth below the zone of at least partial oxidation. In the Carter mine there has been a small degree of oxidation to a depth of about 1,300 feet.

In general the gold and silver values are less where the gangue is pyrite and quartz than where the gangue is limonite and quartz, but the galena commonly carries good values in gold. A sample of galena and quartz taken by the writer from a 6-inch streak on the lowest level of the Gold Links mine and assayed by H. F. Watts of Boulder, yielded 11.76 ounces gold and 15.50 ounces silver per ton, and 15.30 per cent lead.

Data are not at hand for an intelligent estimate of the changes in value that have been effected by oxidation and solution near the surface and probable deposition of secondary sulphides at a lower level.

MINERALS OF THE ORE DEPOSITS

In this section the occurrence and associations of ore minerals and gangue minerals of the region, in so far as they are known, will be briefly noted. Many of the metallic minerals are present in too small quantity for the commercial extraction of their principal component, as, for example, molybdic ocher and the iron oxides; yet some of these carry the precious metals in payable quantity. The metallic minerals are listed alphabetically under the name of the most important contained metal. It is not intended to give here a full general description of each mineral, but only to mention a few characters that the mineral locally possesses. For the convenience of those who may not have in mind the details of composition the formula of each identified mineral is given together with the percentage of the principal metal contained when the mineral is pure.

ALUMINUM

Aluminum-iron sulphate.—A white hydrous sulphate of aluminum and iron with a little copper occurs in decomposed schist at a prospect on the steep slope a few hundred feet northwest of the Raymond mill. The material has not been quantitatively analyzed.

ARSENIC

Arsenopyrite, sulpharsenide of iron, FeAsS—arsenic 46.0 per cent, iron 34.3 per cent, sulphur 19.7 per cent. Small crystals of arsenopyrite, having well developed forms are associated with ankerite and quartz in the Grand Prize mine. Since only a single specimen was secured, the extent of the occurrence of arsenopyrite here is unknown. Arsenopyrite also occurs in the Cortland vein where it forms small crystals and grains associated with dark ruby silver, brittle silver, galena, and quartz.

COPPER

Azurite, basic cupric carbonate, $2CuCO_3.Cu(OH)_2$—copper 55.3 per cent. This mineral occurs as a blue stain with malachite, limonite, and molybdenite in a pegmatite dike near Lamphier Lakes.

Bornite, copper-iron sulphide, Cu_5FeS_4—copper 63.3 per cent Bornite fills fractures in the quartz of a vein on the Bornite claim on the southeast shoulder of Henry Mountain.

Chrysocolla, copper silicate with water, $CuSiO_3.2H_2O$—copper 36.1 per cent. This is found in small quantity as a sky-blue mineral associated with malachite in pre-Cambrian quartzite about three-fifths of a mile southeastward from the portal of the Gold Links tunnel.

Malachite, basic cupric carbonate, $CuCO_3.Cu(OH)_2$—copper 57.54 per cent. This green carbonate is seen in several places within the district, where it evidently has been formed by the alteration of bornite or copper-bearing pyrite. For the most part it occurs only in small quantity as a stain through or on the weathered surface rock or vein material. However, on the Bornite claim good malachite ore was opened near the surface; and about a mile northeast of Henry Mountain the pegmatite of the cliff facing southeast is liberally coated, in spots, with malachite.

GOLD

Gold is the principal metal of most of the mines in the district. In so far as known, it all occurs as the native element. The metal is seldom detected by a megascopic examination of the ore, but the writer has seen it in small grains in specimens from the Gray Eagle mine. Free gold in considerable quantity can be panned from the oxidized ore of several mines and, in small amount, from part of the pre-Cambrian quartzite. Gold has also been obtained by placer mining in Jones Gulch and at Dutch Flat.

IRON

Limonite, ferric oxide with water, $2Fe_2O_3.3H_2O$—iron 59.8 per cent. Limonite is common in the oxidized part of the veins, where it has evidently originated through the oxidation of pyrite (and possibly marcasite) with hydration. In a few places limonite pseudomorphs after pyrite may be seen. The limonite is seldom pure, but is more or less intermixed with other material including magnetite and turgite.

Magnetite, a compound of ferrous oxide and ferric oxide, $FeO.Fe_2O_3$—iron 72.4 per cent. In addition to the magnetite at or near the contact between the sedimentary rocks and intrusive porphyry, this mineral is intimately associated with limonite in the oxidized ores where it probably originated through oxidation of iron sulphide. It forms only a small part of the total iron oxide and can scarcely be detected without panning.

Pyrite, iron disulphide, FeS_2—iron 46.6 per cent. Pyrite is probably the commonest metallic mineral in the district; it is found in nearly or quite all the mines and prospects whose workings have penetrated the sulphide zone. It is also sometimes seen in the schist and quartzite of the glaciated area within a few feet of the surface, where it has been uncovered in shallow prospect holes.

The pyrite occurs both in well shaped crystals and in the massive state. Most of the observed crystals are small, having a maximum diameter of about half an inch. Very commonly they do not exceed two or three millimeters in diameter. The commonest observed forms are cube and pyritohedron, usually in combination. Some specimens from the Cortland mine show aggregates of very small crystals beautifully tarnished golden yellow, red, blue, and green. In so far as known to the writer, large masses of pure pyrite have not been found in this region. The mineral commonly occurs as crystals, grains, or small masses associated with other sulphides, quartz, or, less commonly, ankerite, in veins that vary in width from a few inches to several feet.

Turgite, hydrous ferric oxide, $2Fe_2O_3.H_2O$—iron 66.2 per cent. Red, earthy turgite is associated with limonite in small quantity in the oxidized ores of several mines. Like the limonite it was evidently formed by the oxidation of iron sulphide, with hydration. This mineral is often locally called "red lead," but specimens of the mineral so designated yielded no lead when carefully tested in the laboratory.

LEAD

Cerussite, lead carbonate, $PbCO_3$—lead 77.5 per cent. Crystals of cerussite, gray to white in color, are found in small quantity in the oxidized ores of several mines. Specimens of massive cerussite were collected from a dump about three-fourths of a mile east of the Sacramento mine. Here it occurs in limestone and quartzite. Calamine is associated with the cerussite in the quartzite.

Galena, lead sulphide, PbS—lead 86.6 per cent. Galena is one of the ore minerals of the Bassick, Gold Links, Raymond, Carter, and Cortland mines. Judging from specimens seen at several old mines that are now idle, it has been found in nearly all the mines whose workings have reached the sulphide zone. It has also been found in a few prospects on Fossil Ridge where it is disseminated, as cubes and formless grains, in the limestone which it has partly replaced or in coarsely crystallized calcite that has been deposited in fractures in the limestone.

The galena of the mines is commonly rather coarse, though very fine-grained galena may be seen in places within two inches of the coarsely crystallized mineral. Large masses of pure galena in these mines have not been seen by the writer. Instead, this mineral is very commonly associated with zinc blende, pyrite, or quartz, or with all three.

Pyromorphite, phosphate and chloride of lead, $3Pb_3(PO_4)_2 \cdot PbCl_2$—lead 76.35 per cent. Greenish-yellow to green pyromorphite has been found in small quantity in the oxidized ore of the Gray Eagle, Chloride, Buckeye Chief, Hilltop, and perhaps other mines. The mineral is locally called "chloride." The best specimens collected in the course of the survey of the district came from the Gray Eagle mine. In this mine the pyromorphite forms a thin coating on quartz and on the walls of small cavities in limonite and completely fills smaller cavities in the limonite. To the unaided eye the crystallized character of the pyromorphite is scarcely discernible, but under a strong lens it appears in part moss-like, and in part as small aggregates of minute, radiating, prismatic crystals.

MANGANESE

A black, sooty manganese mineral, intermixed with limonite, was found coating the wall rock in the stope below the tunnel level of the Gold Links mine. Without a quantitative analysis the mineral cannot be specifically determined. The mixture dissolves in hydrochloric acid with the evolution of chlorine, and gives water when heated in a closed tube. The water may be contained largely in the limonite. The black mineral is probably pyrolusite, essentially manganese dioxide; or it may possibly be manganite, hydrous manganese sesquioxide.

MOLYBDENUM

Molybdenite, molybdenum disulphide, MoS_2—molybdenum 60.0 per cent. Molybdenite has been discovered in several places near Lamphier Lakes. It occurs mainly in the quartz of wide pegmatite dikes, but partly in granite adjacent to the pegmatite. The molybdenite is in patches up to two inches in diameter, but is mostly in smaller patches or flakes. The molybdenite forms only a small part of the bulk of the rock. It has been uncovered in several prospects, and at one point can be seen at the surface. A small amount of pyrite is associated with molybdenite at one of the prospects, while copper stain and iron stain are common.

The slowness of oxidation of molybdenite in nature is indicated at one prospect where the mineral is exposed in an open cut to a depth of a few feet and where it also appears at the very surface of the glaciated pegmatite. The quartz is considerably stained by limonite and malachite, but no indication of molybdic ocher could be detected, though the sulphide had been exposed throughout a period sufficiently long for the complete removal of the polish from the glaciated surface of massive quartz. At another prospect a small quantity of molybdic ocher is associated with molybdenite.

Molybdic ocher, hydrated ferric molybdate, $Fe_2(MoO_4)_3.7\frac{1}{2}H_2O$—molybdenum 39.6 per cent. A very small amount of yellow molybdic ocher may be seen as a coating on molybdenite at a prospect near Lamphier Upper Lake.

SILVER

Argentite, silver sulphide, Ag_2S—silver 87.1 per cent. A specimen of ore from the Cortland mine, in the mineral collection at the University of Colorado, shows massive argentite with wire silver, galena, and zinc blende. The ores that were being mined when the Survey party was in the district carried no argentite that could be seen in hand specimens.

Native silver, Ag.—A specimen from the Cortland mine, mentioned under *argentite,* carries numerous patches and tufts of wire silver. The patches, which are one to three millimeters in diameter, are in part closely associated with argentite and in part with zinc blende. Native silver was not seen in the district by the writer, but in addition to its occurrence in the Cortland mine, wire silver is said to have been found in the Volunteer mine.

Pyrargyrite, or *dark ruby silver,* silver sulphantimonite, Ag_3SbS_3—silver 59.9 per cent. Ruby silver is reported to have been found in considerable quantity in the Cortland mine. A specimen collected from this mine shows pyrargyrite, in small patches and formless grains, associated with stephanite, galena, arsenopyrite, and quartz.

Stephanite, or *brittle silver,* silver sulphantimonite, Ag_5SbS_4—silver 68.5 per cent. A specimen collected from the Cortland mine contains a considerable quantity of stephanite in small grains and patches. The mineral resembles gray copper in luster and color, and is associated with pyrargyrite, galena, arsenopyrite, and quartz.

ZINC

Calamine, hydrous zinc silicate, $H_2Zn_2SiO_5$—zinc 54.2 per cent. No calamine was seen in place in the course of the field work, but specimens were collected at several mines or prospects. Specimens of excellent quality were found at the Carbonate King, where the mineral occurs as a drusy coating of colorless crystals and as massive gray-black calamine. At or near Boulder Fault, about half a mile west of Boulder Lake, calamine is found with limonite, as a drusy coating. The same mineral was taken from the Silver Islet mine, where it is gray-black and associated with calcite. Calamine was also found as colorless crystals, with cerussite, in quartzite, at a caved shaft about three-fourths of a mile east of the Sacramento mine.

Sphalerite, or *zinc blende,* zinc sulphide, ZnS—zinc 67 per cent. Sphalerite, in small quantity, is associated with galena and pyrite in several mines within the district. It varies in texture from dense to coarsely cleavable. In color it is commonly dark brown. Exceptions to this are the pale yellow resinous crystals of the Sandy Hook mine and the large aggregates of small, shiny, black crystals of the Cortland mine.

EXCLUSIVELY GANGUE MINERALS

Ankerite, a carbonate of calcium, magnesium, and iron, principally, but usually containing a little manganese, $CaCO_3.(Mg, Fe, Mn)CO_3$. Specimens from the McCarty and Clark tunnel of the Sandy Hook mine show a face of light gray ankerite together with fairly large crystals of pale yellow, resinous zinc blende. The ankerite has crystallized in small rhombohedrons with curved faces. Small crystals of ankerite in flat rhombohedrons are associated with pyrite and vein quartz in the Cortland mine. A specimen from the Grand Prize mine carries rhombohedrons of ankerite with arsenopyrite and quartz.

On one of the Raymond claims a vein of ankerite was opened in a tunnel along the contact between granite and diorite. Here the ankerite, which is cream colored, fills a vein about two inches thick. The crystals, whose forms are somewhat obscure in the specimen examined, interlock with comb structure at the middle of the vein. The mineral turns black when heated before the blowpipe and becomes only very slightly magnetic. An analysis of ankerite from this vein, by H. S. Thayer, follows:

Analysis of ankerite from Raymond mine

[H. S. Thayer, Analyst]

		Molecular Ratio		
MgO	13.02	.323	$MgCO_3$	27.23
CaO	29.00	.517	$CaCO_3$	51.75
FeO	9.84	.137	$FeCO_3$	15.87
MnO	3.02	.043	$MnCO_3$	4.89
CO_2	45.06	1.024	Excess CO_2	.20
Al_2O_3	.33		Al_2O_3	.33
Insol.	.38		Insol.	.38
	100.65			100.65

This specimen contains more manganese than most of the ankerite hitherto analyzed. Of the 60 analyses of ankerite recorded by Leitmeier in Doelter's Handbuch der Mineralchemie[1] 35 show no manganese or only a trace, while the greatest single amount of manganese oxide there recorded—1.87 per cent MnO in number 40—is less than two-thirds the amount found by Mr. Thayer. Nevertheless the analyzed mineral from the Gold Brick district has a much lower manganese content than typical kutnohorite. It is fairly typical ankerite, whether we take the formula of Dana, Naumann, and Rammelsberg—$CaCO_3.(Mg, Fe, Mn)CO_3$—or that of Boricky—$CaFeC_2O_6.xCaMgC_2O_6$—and assume that manganese may replace part of the iron of the latter. The ratio of $CaCO_3$ to $(Mg, Fe, Mn)CO_3$ in the analysis is 1:.973, or nearly 1:1 required by the formula $CaCO_3.(Mg, Fe, Mn)CO_3$. Applying the Boricky formula and using the molecular ratio of the foregoing analysis, we have $Ca(Fe, Mn)C_2O_6.x(CaCO_3.958MgCO_3)$, not greatly different from $Ca(Fe, Mn)C_2O_6.xCaMgC_2O_6$. In the present instance x has a value of about 1.8.

Barite, or *heavy spar,* barium sulphate, $BaSO_4$. A few crystals of barite have been found in the Volunteer vein of the Carter mine.

[1]Vol. 1, pp. 371-376.

Calcite, calcium carbonate, $CaCO_3$. Calcite deposited from solution, occurs not only in the oxidized ore bodies, but also with sulphides in several mines, including the Bassick, Gold Links, and Carter. In the form of limestone calcium carbonate is found with the ore minerals in the sedimentary rocks.

Quartz, silica, SiO_2. Quartz is perhaps the commonest gangue mineral in the region. It is associated more or less intimately with the ore minerals of practically all the mines, excepting possibly those whose deposits are wholly within the limestone. The vein quartz shows all gradations from a dense massive variety to crystals with well developed forms. In some specimens the crystals are long and needle-like but almost microscopic in size.

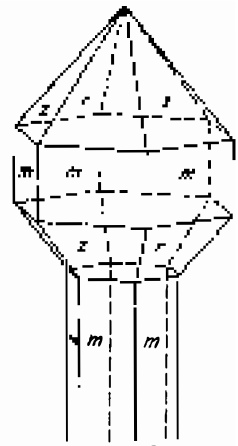


Figure 3. — Quartz crystal from the Cortland mine

Two types of crystal habit are shown by the quartz of the Cortland mine. The first is that of prismatic crystals having rhombohedral terminations at only one end. Most of these crystals in the specimens obtained are less than four millimeters thick and have a length three or four times the thickness. The crystals of the second type are doubly terminated with positive and negative rhombohedron. The prism faces vary in shape from square to rectangular with height about one-half the width. The crystals accordingly are stout; the maximum horizontal diameter is about one centimeter. These crystals were formed later than those of the first type, and are very commonly perched each on a smaller prismatic crystal in parallel position, thus forming so-called "scepter quartz." Figure 3 illustrates a typical specimen.

GENESIS OF THE ORES

The base metals were evidently originally deposited as sulphides from metal-bearing solutions that carried also a slight amount of gold and silver. The gold and silver may have been precipitated mainly in the metallic state, but the silver of the Cortland vein is in part combined with other elements.

Proof or even convincing evidence of the source of the metal-bearing solutions is lacking. However, the apparent absence of extensive mineralization of the limestone points to the probability that circulating ground water has carried in solution only a slight amount of metal since the sediments were faulted and fractured.

Further evidence of this is found in the extensive faulting that cuts off the veins in the Gold Links and Carter mines, and is hence certainly younger than the ore-bearing veins. These faults probably are of the same age as those in the sedimentary rocks and are therefore later than early Pennsylvanian.

The principal ore-bearing veins are found in both granite and regional-metamorphic rocks and for the most part near the contact between the two. The fissures in the gneiss and schist were probably caused by faulting prior to the solidification of the granite; gouge, which is so common in the veins in the gneiss and schist, has not been seen by the writer in ore-bearing veins in the granite. The fissures in the granite may owe their origin to contraction of the crystallizing and cooling crust of the granite body. Fissures so formed and also the fault-fissures in the metamorphic rocks could become the channels for waters emanating from the incompletely solidified magma within.

The possibility of a concealed source of the ores might be mentioned. The Princeton quartz-monzonite or granodiorite batholith outcrops 5 or 6 miles east of this region, and may have a westward extension not far below the surface. But if magmatic solutions of metals from this post-Paleozoic intrusion had reached the fissures in metamorphic rocks and granite of the Gold Brick district they would in all probability likewise have carried metals to the nearby limestone.

The best available evidence therefore seems to favor the hypothesis that the bulk of the ore was deposited, probably in pre-Cambrian time, from magmatic solutions emanating from the cooling granite that had invaded the older rocks.

It is probable that the ores found in the limestone and those at contacts between the porphyries and older rocks owe their origin to late intrusions, and were perhaps deposited in Tertiary time.

FUTURE POSSIBILITIES

It is highly probable that the known ore—especially low-grade ore—has not been exhausted in more than a few, if any, mines of this district. Certain it is that much low-grade ore may be seen in most of the mines that can now be examined. Further, in Jones Gulch and between Jones and Hills gulches there are strong veins that have been only superficially prospected on certain claims. The same is probably true of other localities where, on account of the caved condition of old mines and prospects, the opportunities for examination are few.

Much of this ore could doubtless be profitably mined if suitable milling facilities were close at hand. Perhaps for only a short time each year is the water supply adequate for milling by present methods locally employed, except in Gold and Quartz creeks. These creeks are too far from the veins mentioned to encourage the owner of a single claim or of a small number of claims to undertake extensive developments. The same veins could probably be most economically developed through the three tunnels opening on Gold Creek where there is abundant water for milling purposes. Several veins nearer Gold and Quartz creeks and in McIntyre Gulch are sufficiently promising to warrant further development.

The large body of pre-Cambrian quartzite west of Revenue Gulch is said to carry quite uniformly gold in sufficient quantity to make profitable mining seem possible. The Survey has not undertaken any systematic sampling of this quartzite.

There does not seem to have been more than slight mineralization of the limestone in the Gold Brick district, though structural conditions are almost ideal for the circulation of solutions and the reception of ore minerals. The apparent scarcity of metals here may be correlated with the small quantity of igneous rock—and that mainly andesitic—that was intruded subsequent to the folding and faulting of the strata. Conditions in the limestone are somewhat different in the Quartz Creek district—partly within the area mapped—where acidic rocks of unknown extent are intrusive in the limestone.

DESCRIPTIONS OF MINES

The mine descriptions that follow are based on observations that were made chiefly in the summers of 1911 and 1912. The Carter, Sandy Hook, Granite Mountain, and Gray Eagle properties were visited in 1914.

Since the workings of many of the former producers were inaccessible when the Survey party was in the field, there is but little information at hand concerning them. The names of the claims that were formerly producers, in so far as they could be learned, are listed in this chapter under the heading "Other Mines Formerly Productive."

CORTLAND MINE

The Cortland mine was opened by an inclined shaft 280 feet deep and by five short adits. In 1912 it was possible to examine the veins, at shallow depths and for short distances, in the upper adits. The main vein is at least two feet wide, where seen at a distance of about 1,000 feet north of the shaft, and is in schist similar to the veins of the Gold Links and Raymond mines. It strikes N. 25° E. and dips toward the west 45° to 60°. A strong fault striking N. 35° W. and dipping 50° to 60° southwest is cut in one of the tunnels. The details of structure have not been worked out, but the horizontal throw on the southwest side of the fault is evidently toward the northwest.

The fault is best seen in No. 4 tunnel where the faulting is marked in places by a sharp break with a narrow streak of gouge, and in other places by a fault zone 10 feet wide. In the latter, while there is considerable fracturing in small pieces, there are many large, unbroken blocks of gneiss and schist. On this level the vein was followed 140 feet, and three or four carloads of ore were shipped from it. Some low-grade ore was taken from a drift on the fault. The ore body at the intersection of fault and vein was larger than elsewhere in the vein on this level. A small cross-fault showing breccia, stops at the main vein and is hence older than the vein filling. The best ore was near the main fault and the next best was about 100 feet nearer the portal where there are two veins that meet but do not cross. The main fault fissure is filled in places by masses of uncrushed galena and pyrite with crystals of quartz, thus showing that mineralization was in part subsequent to the faulting. The ores of these shallow workings were in part oxidized, carrying values in gold and silver, but in large part sulphides of lead, zinc, and iron. Sulphides were found within 40 feet of the surface.

One carload of sulphide ore from No. 4 tunnel is reported to have returned $65 per ton in gold and silver. In No. 2 tunnel, where the vein has been followed 60 feet, high-grade silver ore was mined in a winze. This was chiefly wire silver and argentite with galena and pyrite.

The Cortland shaft, which was full of water when the mine was visited, was sunk on the vein, which dips westward. Mr. H. S. Roe, who located the Cortland, kindly furnished most of the information given below.

The shaft is 280 feet deep; drifts were run at levels of 50, 100, 150 and 200 feet. The longest of these is at the 100 foot level, where the vein was drifted on 1,690 feet northward and 72 feet toward the south. Ore was stoped out above all the levels down to 200 feet. The vein runs from the thickness of a knife-blade to

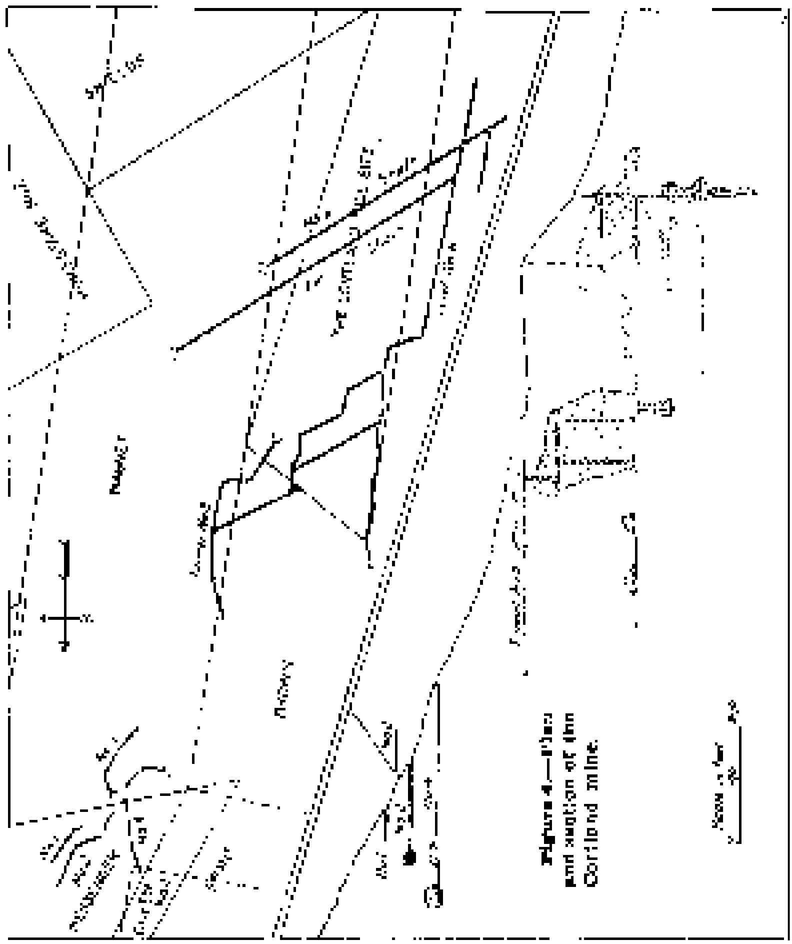


Figure 4.—Plan and section of the Cortland mine.

five or six feet, with an average of about three feet. The ore is in shoots dipping southward about 50°. (See fig. 4.)

The ore is said to be chiefly silver-bearing galena in a gangue of quartz and pyrite. Most of the ore is said to have run $60 to $150 per ton. The report of the Director of the Mint states that the Cortland was a regular shipper in 1902, the ore running as high as $100 a ton, values mostly gold.

The Cortland mine is now owned by the Queen Mining Company which is planning further to develop the property. Mr. J. S. Lewis, secretary of the company, states that about $40,000 worth of crude ore has been shipped from the mine and that there is about the same amount of mill ore on the dumps and broken in the stopes ready for milling. Under date of August 19, 1915, Mr. Lewis states that the company has resumed work in the mine and expects soon to be shipping ore.

Vein minerals reported from this mine—some only from near the surface—are the following: wire silver, argentite, ruby silver, stephanite, tetrahedrite, galena, zinc blende, pyrite, arsenopyrite, and quartz. The writer has seen, in specimens from the mine, all the minerals named except tetrahedrite. Gold has not been seen in specimens from the mine, but most of the ore is said to run about $10.00 per ton in gold. Many fine specimens of crystals, some of them beautifully colored, have been taken from the Cortland mine. It is said that the first $1,000 spent in developing the property after the discovery of the minerals, was received from the sale of mineral specimens for college and museum collections. Mention has been made of some of these minerals in the section on "Minerals of the Ore Deposits" in this bulletin.

The mine is equipped with a steam hoist and three pumps.

CARTER MINE

The Carter Mining Company owns a large tract, including several claims that were formerly producers, in and near Dutch and Jones gulches. Two of the old producers now owned by the Company are the Volunteer mine and the Golden Islet mine.

The Carter mine (Pl. VII, A) is operated through a tunnel which runs about S. 55° E. a distance of 6,550 feet. Through the first two-thirds of its course, approximately, the tunnel is in gneiss. The remainder is in granite excepting about 100 feet where the tunnel passes through two porphyry dikes about 5,000 feet from the portal. One of the dikes measures about 90 feet on the tunnel level, but it is probably crossed obliquely. The breast of the tunnel is probably 1,400 feet, or more, below the surface. A raise of 1,100 feet, started in a crosscut from the tunnel, at a distance of nearly 2,000 feet northeast of the tunnel, connects the tunnel level with the old Volunteer mine workings.

At the time of the writer's visit to the mine, in August, 1914, ore was being mined in the Volunteer vein which had been opened by crosscuts from the upraise and drifts on the vein at the ninth, tenth, and eleventh levels, while a crosscut was being driven to cut the vein on the eighth level. (In the Carter mine the levels, at intervals of 100 feet, are numbered consecutively from the tunnel level upward, the eleventh level being 1,100 feet above the main tunnel level.)

Many veins, including the Golden Islet, were crosscut by the tunnel, but they have hitherto yielded only a comparatively small quantity of ore. Ore has been taken from seven or eight veins, including six in the gneiss and one at a contact between porphyry and granite. The ore came chiefly from drifts on the tunnel level, though a little stoping has been done on four or five veins.

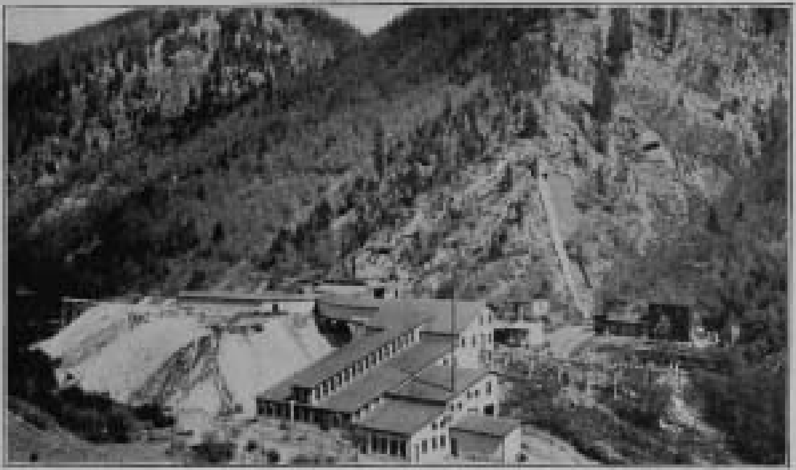
Volunteer vein.—In 1914 the vein was seen by the writer at the ninth, tenth and eleventh levels, where ore was being mined. On these levels the vein strikes N. 15° to 20° E. and dips eastward at a high angle. On the eleventh level the vein dips but slightly from vertical toward the east, but on the ninth level the dip was 65° eastward where the vein was seen. In the old Volunteer mine workings, nearer the surface, the dip is toward the west. In its strike and peculiarity of dip the Volunteer vein is very similar to the Chloride vein.

When the mine was visited the drift on the ninth level was only 60 feet long; and the vein, where seen, was not so well defined as at the higher levels. The vein filling exposed was mainly quartz and pyrite, but galena was reported to have been found in the best ore of this level.

On the tenth level the north and south drifts had a combined length of 275 feet. The lead varies here in width from 6 inches to 4 feet and has an average width of about 2½ feet. In places two or more filled fissures are separated by granite. This granite is usually much decomposed and is said to carry values in gold and silver. The same is true of the granite walls of the vein, in places. The ore of this level is reported to run $5 to $100 per ton in gold and silver. These values are carried chiefly by limonite and iron-stained quartz. Only a small amount of pyrite is present on this level.

On the eleventh level the vein had been followed only about 100 feet in August, 1914. South of the raise faulting had displaced the vein. The ore of this level was about one foot wide and was being stoped upward. The ore of this level is similar to that of the tenth, but contains less pyrite.

The Volunteer mine, on the upper part of this vein, is one of the oldest mines in the district and, according to the Mint reports, it was a fairly steady producer through the eighties—at least from 1882 on. The report for 1882 states that the "ore mill-runs $60



A. CARTER MINE AND MILL

B. RAYMOND MINE AND MILL

per ton, three-fifths gold and two-fifths silver; vein in tunnel 4½ feet wide, all in mineral.'' The same authority reports that the mine produced steadily in 1883. The report for 1884 credits shipments of two carloads of ore, and states that at the bottom of the shaft 100 feet below the tunnel level ''the pay streak is 2½ feet wide and runs over $100 to the ton.'' The report for 1888 gives the output of the mine for that year as follows: gold $4,500, silver (coinage value) $1,939.35. For other years the output of the Volunteer is included with confidential reports by the Director of the Mint. Mr. C. M. Carter states that the most reliable estimates that he could get place the total output of the Volunteer at approximately $500,000.

The old Volunteer mine was opened by tunnel and winze to a depth of 240 feet. The stope of the lowest level is said to be 600 feet long, and for a much shorter distance the ore was stoped from this level to the surface. Nearly all the ore mined was oxidized.

Golden Islet vein.—A drift on the Golden Islet vein on the tunnel level showed, when examined by the writer in 1911, a streak of solid sulphide ore one-half inch to three inches wide throughout the length of the drift and in the breast. The ore is mainly gold- and silver-bearing galena with a little pyrite.

Mr. Carter later reported that the drift had been continued to a length of 600 feet with the breast still about 350 feet south of the winze mentioned below. It is also stated that the vein reached a width of 3 to 7 feet near the breast of the drift, and contained low-grade ore. This drift is probably between 700 and 1,000 feet below the surface.

The old Golden Islet mine, on the upper part of this vein, was worked in the eighties. The Mint report for 1889 credits it with an output for that year as follows: gold $1,440, silver (coinage value) $209.45. The writer has not found any other mention of this mine in the Mint reports.

The vein is in gneiss or schist and reported to be 2 to 7 feet wide. The mine was opened by three short tunnels and a winze 75 feet from the lowest tunnel.

Equipment.—A 20-stamp amalgamating and concentrating mill stands just below the portal of the Carter tunnel. Most of the ore mined is treated in this mill, but some high-grade ore is sorted out, and shipped in the crude state.

Three water wheels propel the mill machinery, generator, and air compressor. Air drills have been used in the mine several years, but the tunnel was driven by hand many hundred feet during the first years of work. The mine and mill buildings are electrically lighted. Pure water for domestic use is piped from a fissure that is crosscut by the tunnel.

RAYMOND MINE

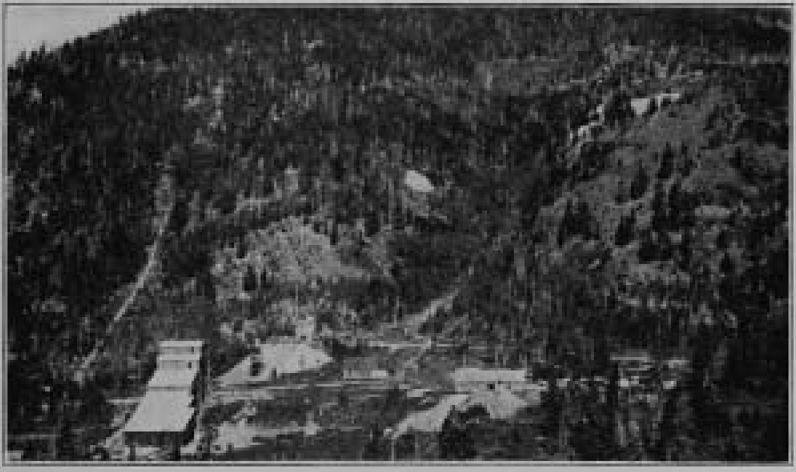
The Raymond mine (Pl. VII, B), owned by the Raymond Consolidated Mining Company, was the first in the district to be developed at a considerable depth by a tunnel. It has also been one of the largest producers in the county. In 1911 it was visited by Mr. Coffin and the writer at a somewhat inopportune time when mining operations were practically suspended and there was little chance to examine the geology and stopes in detail. However, Mr. W. E. Draper, the foreman, kindly showed us through the workings, in so far as was convenient, and furnished much of the information noted below. The figures are in part approximate.

The tunnel runs S. 73° E. a distance of nearly 3,000 feet. For the first half of its course, approximately, the tunnel crosscuts pre-Cambrian gneiss and schist; the remainder is in granite. The breast is about 800 feet below the surface, according to the topographic map which accompanies this bulletin. Nine leads were cut, of which three are in granite and six in the gneiss and schist. Drifts, each between 50 feet and 600 feet in length, were run on seven leads, and ore has been stoped from five of them.

The first workable vein is about 600 feet from the portal of the tunnel and carries a pay streak six inches to one foot wide. The stope here is only 25 feet long by 30 feet high. The second vein, 950 feet from the portal, has a stope 200 feet long by 225 feet high; the ore here was 1 to 6 feet across. The third vein, 1,100 feet in, had about 2½ feet of ore by 400 feet, horizontally, and was stoped upward 250 feet. The fourth vein, at 1,200 feet from the portal, has a stope 100 feet long by 80 feet high, and ore a foot to a foot and a half thick. The fifth vein, at 1,600 feet, had workable ore 2 to 4 feet thick and a stope 50 feet long by 225 feet high. At the time of our visit not all the known ore had been removed.

The ore is chiefly gold-bearing galena and pyrite in a gangue of quartz and gouge or decomposed schist. In places the ore is cut off by bunches of schist up to 30 feet in longest diameter. Pegmatite, in lenticular masses, is not uncommon in the leads. While assays of rich streaks may run as high as 8 ounces in gold,

A. GOLD LINKS MINE AND MILL



B. SANDY HOOK MINE AND MILL
Chronicle mine near upper right-hand corner

most of the ore is of much lower grade. It is said to average 1½ to 2 ounces gold per ton and carries 10 to 33 per cent lead. Silver runs only from a trace to half an ounce per ton.

The old Raymond mine, in Spring Gulch, is reported to have produced considerable ore from comparatively shallow workings. It is probable that one of the veins of the tunnel is the same as that from which ore was taken in the old mine, though it is not known to the writer whether or not the ore is continuous from the old to the new workings. The Jessie vein, which yielded high-grade ore in the early days, was barren where it was cut by the Raymond tunnel.

Equipment.—The mine is equipped with boilers, air compressor, and seven machine drills, ventilated by an electrically driven blower, and lighted by electricity. Steam power is used for most of the machinery of mine and mill; the electric generator is run by water power, supplemented when necessary by a small steam engine. All mine and mill buildings are lit by electricity.

The ore is in large part treated in the Company's amalgamating and concentrating mill near the portal of the tunnel.

GOLD LINKS MINE

The Gold Links mine (Pls. IX and VIII, A), owned by the Colorado Smelting & Mining Company, has been the largest producer of the district in recent years. Production was practically continuous from October, 1908, to December, 1912. The mine has produced nearly $600,000 worth of ore, after deducting freight and treatment charges. The values are chiefly in gold.

The mine is operated through a tunnel running S. 65° E. about 3,900 feet. The tunnel, which was driven in gneiss and schist across the schistosity, encountered one porphyry dike and six ore-bearing veins. Only one of the veins has been developed. This vein, which is crosscut by the tunnel at 2,150 feet from the portal, has been drifted on about 500 feet toward the south and 1,500 feet toward the north from the tunnel.

In the north drift, about 1,500 feet from the tunnel, the vein is faulted through a distance and in a direction not yet certainly determined. The rock is more or less crushed and slickensided through a zone many feet wide, as may be seen in several drifts and crosscuts driven to prospect the fault zone. In the stope below the tunnel level the ore is faulted off by a plane dipping 27° N. 40° E., but it is probable that this dip and this strike are local.

It is highly probable that the fault zone trends northward as mentioned in the chapter on structural geology. The principal faulting evidently occurred after the ore was deposited.

At a point about 1,350 feet from the tunnel, in the north drift, a winze was sunk to a depth of 85 feet. At this depth the vein had been drifted on, when the mine was visited, both north and south of the winze through a total distance of 500 feet. In 1912 ore was being stoped between the two levels and above the tunnel level. The greatest height reached at this time was 275 feet, on the pitch, above the tunnel level. The distance on the pitch through which the vein could be examined in 1912 was therefore 360 feet.

The vein parallels the planes of schistosity of the country rock and dips westward 30° to 75°; the dip is commonly high. It is difficult to name the wall rock specifically. For the most part it appears to be a somewhat kaolinized, highly quartzose gneiss or quartz schist which now contains many small flakes of talc or sericite. It is partly replaced by small crystals of pyrite, while the same mineral fills many small fractures in the rock. Part of the quartz of the wall rock appears to have been deposited from solution. Locally lenslike masses of pegmatite are close to the vein, and where this is so the ore is likely to be lean.

It is likewise difficult to name the vein type. In places the walls are well defined, there being a sharp boundary between vein filling and wall rock. Again, there may be a gradation from good ore to barren rock, the wall being merely the limiting border of ore that can be profitably mined. Where the wall is of this character as well as in parts of the vein, the ore minerals clearly replace part of the original rock, as can be seen by the form and relationships of the minerals. In places there is a distinct, though not pronounced, banding of the vein minerals: galena, zinc blende, pyrite, and quartz. This crustification was evidently brought about, mainly if not wholly, by the successive deposition of different minerals in an open fissure. The uniformity in strike and absence of great variation in dip of the vein also strongly suggest an original fissure of considerable extent. The vein can perhaps be most accurately characterized as a fissure vein that has been materially widened, in many places by metasomatic replacement.

In general, the vein varies in width from a few inches to eight feet with an average of about four feet. At one place on the tunnel level the vein had a width of 23 feet. Where seen by the writer on the 85-foot level and in the stope above this level, the vein proper varied from a few inches to eight feet in thickness, but locally the foot-wall was mineralized to a distance of at least two feet from the vein.

Most of the ore on the tunnel level and below is sulphide ore, galena and pyrite with a little zinc blende; but even in the deepest workings small patches and narrow streaks of the sulphides have been oxidized. Here limonite or a mixture of limonite and an oxide of manganese may be seen. In the highest stopes of the mine the ore contains much limonite—sometimes copper-stained—with small patches of galena and a little residual pyrite. The proportion of metallic minerals to non-metallic varies greatly. Locally masses of galena and pyrite with perhaps a little zinc blende may carry almost no non-metallic material. Again, the metallic sulphides may be sparingly disseminated through the vein. Generally, the proportion lies between these two extremes.

By far the greater part of the ore is treated in the company's amalgamating and concentrating mill, though a considerable quantity of crude ore has been shipped directly to the smelter. The ore carries values in gold, silver, and lead. Data as to the average value of the ore as it comes from the mine are not available, but it is known that the gold content varies from a small fraction of an ounce to 4 ounces per ton in the oxidized ore and to 11 or 12 ounces per ton in the sulphide ore. The higher values mentioned for both oxide and sulphide ores are unusual. A sample of mixed galena and pyrite from the narrowest part of the vein on the 85-foot level, assayed by Mr. H. F. Watts, of Boulder, gave the following results: gold 11.76 ounces, silver 15.5 ounces per ton, lead 15.3 per cent. The following is the tenor of the concentrates, as taken from the smelter settlement sheets for a large number of shipments: gold 2.17 to 4.095 ounces per ton; silver 7.4 to 11.9 ounces per ton; lead 7.7 to 14.0 per cent. The zinc content of the concentrates is never high enough to entail a penalty at the smelter.

On the main tunnel level, though the vein was lean in spots, the ore was practically continuous through the 1,500 feet of the north drift. Nearly all the rock broken in driving this drift was run through the mill. There are barren, or nearly barren, spots in the vein above the tunnel level. Below the tunnel level, pay ore was continuous in the vein as far as it was opened, when visited by the writer. In addition, a vein two to six feet wide, carrying good ore, and meeting the main vein at a small angle, had been drifted on about 50 feet.

Equipment.—A 40-stamp amalgamating and concentrating mill stands near the portal of the Gold Links tunnel. The mill and also the air compressor that runs the drills are driven by water power between three and four months of each year when the mine is operating. Steam supplements water power during the rest of the year, and for about seven months of each year most of the power used is steam power. To provide for a possible emergency steam is kept up whenever the mine is in operation.

Water power runs a small electric generator throughout the year to furnish light to all the mine and mill buildings, including boarding-house and bunk-house.

SACRAMENTO MINE

Evidently this mine was formerly one of the largest producers of the district, but it has not been worked in many years. It was operated through three tunnels driven on the vein through most of their length. An old map shows that much ore was stoped above the middle and lower tunnel levels and above an intermediate level between the middle and lower tunnels. A smaller amount of stoping is shown above the first, or upper, level.

The vein, which is in gneiss or schist, strikes northward and has a westward dip. It and the Gold Links vein are very probably one and the same, though interrupted by faulting.

The Sacramento mine is now owned by the Colorado Smelting and Mining Company.

BASSICK MINE

This mine, owned by the Bellzora-Bassick Mining Company, has been opened by three tunnels—Monte Vista, Bassick, and Mutual. Mining was in progress on only the lowest level, the Mutual, when the Survey party was in the field.

The Monte Vista adit, which is now caved, was driven eastward about 150 feet in quartz-bearing porphyry to the porphyry-gneiss contact where ore was mined in a drift 200 feet long. Four carloads returning about $35.00 a ton, are reported to have been shipped. The ore was mostly silver-bearing galena and iron oxide with a little lead carbonate. Specimens of mineralized porphyry on the dump, evidently from near the contact, contain veinlets of galena and numerous small crystals of pyrite.

The Bassick tunnel, about 100 feet lower, is said to run southward about 800 feet on the porphyry-gneiss contact. The values here were principally in gold with some silver and lead.

PLAN OF THE GOLD LINKS MINE

The Mutual tunnel was driven S. 70° E. about 1,280 feet in porphyry and gneiss, the first 550 feet being in porphyry. When the mine was visited a drift had been run northward on the porphyry-gneiss contact 90 feet, and another on the same contact, toward the south, 77 feet. An upraise had been driven 30 feet in ore. This is on the same contact as that of the upper levels and about 300 feet lower, vertically, than the ore of the Monte Vista. The pitch length is somewhat greater than this, since the contact and ore shoot dip westward 65° to 72°. The ore is mainly galena with a little pyrite. With these minerals is a small amount of calcite. Good shipping ore extended along the drift about 25 feet and had a maximum thickness of 15 inches. The ore is said to average 3.5 ounces gold and 10 ounces silver per ton and about 15 per cent lead. The porphyry is mineralized with crystals of pyrite and veinlets of galena for two to six feet from the contact, and is said to be of grade suitable for milling.

SANDY HOOK AND CHRONICLE MINES

The mine property of the Sandy Hook Mining Company includes the Sandy Hook proper, having about 2,500 feet of developments and the old Chronicle mine. The mine equipment includes an air compressor and a steam hoist. A 20-stamp amalgamating and concentrating mill was built in 1912 not far from the portal of the Sandy Hook tunnel. (See Pl. VIII, B.)

Sandy Hook mine.—The Sandy Hook tunnel was driven N. 56° W. about 900 feet through gneiss and schist at a high angle to the planes of schistosity. At about 435 feet from the portal a drift was run S. 17° E. about 160 feet on a narrow vertical vein. Here there is much gouge and a little pyrite.

At about 800 feet from the portal of the tunnel a drift was run southward several hundred feet, nearly parallel to the schistosity. For about 100 feet the drift follows the main vein of the workings. Where opened, the vein was from a few inches to five feet in width on the tunnel level, with an average of three or four feet. The vein dips about 63° N. 70° W. An upraise 296 feet long, on the vein, connects the drift on the main tunnel level with the McCarty and Clark tunnel. The latter tunnel cuts the vein 142 feet, on the pitch, from the surface. The Prange shaft was sunk 80 feet on the same vein. The vein has thus been explored nearly all the distance to a depth of 438 feet, on the pitch.

In the raise connecting the main tunnel level with the McCarty and Clark tunnel the vein will average three to four feet in thickness. More or less pyrite shows nearly all the way, and a little galena can be seen near the hanging wall on the level of the McCarty and Clark tunnel. Specimens from this tunnel show also a little coarsely crystallized zinc blende.

In 1914 the property was under lease to Morris Brothers who were prospecting the quartz-bearing porphyry south of the mine and had taken out several tons of ore when the writer was in the district. The ore seen was in iron-stained streaks in the porphyry, but no well-defined vein was exposed. A sample of the ore, assayed by H. F. Watts of Boulder, yielded 2.54 ounces gold and 11.20 ounces silver per ton. A sample of talus containing some soil, from above the mineralized porphyry carried .02 ounces gold and 2.10 ounces silver per ton, as determined by Mr. Watts.

Chronicle mine.—This is one of the oldest producers of the district, but it has been idle for many years. A large dump would indicate that the workings were extensive. (See Pl. VIII, B.) The shaft through which the ore was hoisted is now caved. The waste rock on the dump is mainly gneiss and schist. Specimens of pyrite and galena were seen in the ore bin.

The Report of the Director of the Mint for the calendar year 1883 contains the following note:[1]

> At the Chronicle, on Sheep Mountain, a tramway 1,500 feet long has been built recently, connecting this mine with concentrating works. The vein is from 6 to 10 feet wide; the ore is pyrites of iron and galena, worth from $15 to $20 per ton. The developments consist of a shaft 75 feet deep. A tunnel 188 feet long connects with the bottom of the shaft. The concentrator consists of 10 stamps and 2 Frue vanners, capable of handling 40 tons of ore per day, the concentrates being worth from $65 to $90 per ton.

The Mint reports give the output of individual mines for only a few years. In the reports for the years 1889 to 1892 inclusive, the total output of the Chronicle for these four years is given as follows: gold $2,100, silver (coinage value) $34,473, lead $1,566.

GRAND PRIZE AND CHLORIDE MINES

The Grand Prize and Chloride claims, with twelve other patented claims, are owned—or were in 1911—by the Grand Prize Mining & Reduction Company. In company with Manager Mark Hirsch and Foreman James Barnhill, R. C. Coffin and the writer saw most of the mine workings; but the figures given below were

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furnished by Mr. R. H. Atherton who had a record of surveys and measurements.

The mines are opened by a shaft on the Grand Prize claim and by a shaft and adit tunnel on the Chloride claim. The Grand Prize shaft is equipped with steam engine and hoist, but the mine has been worked in recent years only through the adit which, starting on Chloride ground, cuts the Grand Prize vein about 700 feet from the portal.

The Grand Prize shaft, including sump, is 109 feet deep, and was sunk on the Grand Prize vein proper. The vein, which is nearly vertical, dips eastward at a high angle, strikes N. 12° to 15° E. and, like the other veins of the group, traverses granite.

At the 50-foot level the vein was drifted on 85 feet north and 525 feet south. At the 100-foot level, a drift was run 200 feet north from the shaft and 263 feet south to a split in the vein. From this point the main drift continues southward 150 feet, while a second drift follows the branch of the vein toward the right 56 feet. A raise of 146 feet connects a crosscut on the tunnel level with the 100-foot level at a point 45 feet south of the shaft. A third level, 170 feet below the surface, has a north drift 85 feet long and a south drift 171 feet long. On the tunnel level, 246 feet below the surface, the vein has been drifted on 130 feet north and 200 feet south.

South of the shaft the ore has been stoped from the 100-foot level to the surface. The raise from the tunnel level to the 100-foot level was driven in ore. When the mine was visited ore had been stoped about 35 feet above the tunnel level.

Two or three carloads of ore have been stoped from a second vein which strikes N. 46° E. and crosses the main vein near the raise.

The width of the shipping ore in the main vein is said to have been 2 to 20 inches wide, while the vein itself is 2 to 6 feet wide.

The Chloride shaft is 285 feet deep and sunk on the main Chloride vein which strikes N. 20° E., and dips westward at a high angle, down to the 200-foot level but dips eastward below that level. It is reported that the Chloride vein has been stoped, for 500 feet along its course, from the 200-foot level to the surface, and that a second vein has been stoped from the 100-foot level to the surface through 75 feet of its course. The second vein crosses the main vein and strikes N. 62° E.

The Grand Prize vein includes, within its maximum width of 6 feet, some altered and mineralized granite that is reported to be of milling grade where adjacent to the shipping ore. The Chloride vein is similar to the Grand Prize vein. The wall rock of these veins is highly quartzose, somewhat kaolinized granite of medium to coarse grain. A narrow streak of partly decomposed micaceous schist or fine-gneissoid granite not uncommonly accompanies the ore. Small masses of pegmatite are sometimes found near the vein.

The values are chiefly in gold which is carried mainly by limonite. Free gold can be panned from the crushed ore. The smelting ore on the tunnel level is said to run $48 to $80 a ton. Higher-grade ore was mined on the 100-foot level. The ore of the Grand Prize vein is oxidized from the surface to the tunnel level, that is, to a depth of nearly 250 feet, excepting small bunches of residual galena and pyrite. Limonite, a little turgite, and an occasional malachite stain are the metallic compounds that are easily detected. The limonite forms the bulk of the best ore. Small quartz crystals are common.

The ore of the Chloride vein was in part oxidized and carried some pyromorphite, whence the name of the mine "Chloride." It is said that the Chloride galena ore assayed as high as 34 ounces gold and 35 ounces silver per ton.

The output of the Grand Prize mine, prior to 1911, was shown by the company's books to be $51,096 net—that is, after paying freight and treatment charges. According to Mr. Atherton the Chloride mine has produced about $175,000 worth of ore.

GRANITE MOUNTAIN MINE

In 1914 this mine was being worked under lease by a small force, and the lessees had shipped three small carloads of ore before the last of August. The shipments are said to have yielded, by smelter returns above freight and treatment charges, $55.65, $87.16, and $90 per ton respectively. The mine had previously produced ore, but there is at hand no record of the total output.

The older workings are partly caved, but the vein was seen by the writer where disclosed by the lessees' developments. The mine has been opened by two short tunnels and a winze from the higher tunnel. The winze is 100 feet deep and probably reaches a depth of 200 feet below the surface. The upper tunnel is said to have followed the vein 350 or 400 feet. Drifts, run north and south from the bottom of the winze, are said to have a combined length of 100 feet.

On the lower tunnel level—about 50 feet higher than the bottom of the winze—the vein strikes N. 20° E. and dips 70° westward. The vein is in granite and will average over 3 feet wide where seen. Of this 6 to 24 inches is ore—mainly limonitic quartz. A sample from this level assayed by H. F. Watts of Boulder ran 3.60 ounces gold and 72.90 ounces silver per ton.

A narrower vein, 80 feet east, parallels the main vein, and is said to carry good values in gold.

LUCILLE MINE

The Mint report for 1882 states that the Lucille had at that time 373 feet of shafts, tunnels, and drifts; a vein 12 to 14 feet between walls, with 4 feet of pay ore; and that the milled ore, treated in a 10-stamp mill, ran $100 per ton.

The ore to be seen at the portal of the lower tunnel is pyritic quartz and quartz schist. The gangue is hence similar to that of the Gold Links, Raymond, and Cortland mines.

GRAY EAGLE MINE

Although the Gray Eagle claim was located many years ago it has only in recent years undergone any considerable development. Some high-grade gold ore was produced in 1912 to 1914, but the efforts of the owners have been confined chiefly to development work.

The mine is opened by a tunnel about 1,100 feet long which trends southward and reaches a depth in the breast of nearly 400 feet. For about 800 feet of its course the tunnel was driven on the principal vein which has a westward dip varying between 40° and 80°. The foot-wall is granite. The hanging wall is partly granite and partly a micaceous gneissic granite or schist similar to rock in contact with the Grand Prize vein.

The vein is about 1 to 6 feet wide, and carries bunches or shoots of ore 4 inches to 2 feet wide. The gangue is chiefly quartz and iron oxide with some pyromorphite. The gold is carried mainly by limonite intermixed with a small amount of magnetite. The best ore is said to assay about 20 ounces gold and 10 to 20 ounces silver per ton. Small grains of free gold can be seen in hand specimens, while samples of good ore yield a long string of colors on panning.

The highest raise at the time of the writer's visit to the mine in September, 1914, had reached 85 feet above the tunnel level, and was driven in ore. The ore in the raise was more or less mixed with quartz, broken rock, and gouge—evidently the result of faulting in the plane of the vein or intersecting the vein at an acute angle subsequent to the deposition of ore. Similar conditions were observed in the back of the main drift, or tunnel.

A fault striking eastward and dipping south at a high angle had been followed 200 feet by a drift. The fault fissure carried several inches of gouge and small patches of ore, and had slickensided walls. Three small veins striking nearly north and dipping west were cut by the east drift.

HILLTOP MINE

Two veins, probably the same as those of the Granite Mountain mine, have been opened on the Hilltop claim. Both strike about N. 40° E. and dip northwest at a high angle.

A shaft 80 feet deep has been sunk on the west vein, and a drift has been run about 35 feet on the 40-foot level. The vein is said to be about 3 feet wide with 18 inches of ore. The ore on the dump is limonitic quartz and granite. A small amount of galena was found at the bottom of the shaft. A small shipment netting $173 per ton is reported from this shaft.

A shaft has been sunk 70 feet on the east vein. At the bottom of the shaft a drift has been run northeast 40 feet and 15 feet southwest. Northeast of the shaft ore is said to have been stoped to a height of 15 or 20 feet above the drift. The ore is mainly limonitic quartz and rotten granite, with a small amount of cerussite.

MAGGIE MITCHELL MINE

This is one of the old producers that have not been operated in recent years. The Mint report for 1882 states that the Maggie Mitchell had then over 150 feet development on a vein 5 feet wide with a fine pay streak, and that a 5-ton mill run had yielded $35 per ton.

The big dump and large quantity of low-grade ore that are now to be seen at the mine indicate extensive developments on a strong vein. The vein is in granite, strikes east of north, and dips westward. It is very probable that the same vein is opened on the Granite Mountain and Hilltop claims.

SILVER ISLET MINE

The Silver Islet mine, though in the Quartz Creek mining district, lies within the area represented by the accompanying map. The mine has been idle many years, and the workings, which were in limestone, are now caved. Mr. A. E. Reynolds states that the mine reached a depth of 200 or 300 feet, where a barren natural cave was encountered.

No complete record of the mine is available, but the United States Mint report for 1882 states that the mine then had "1,300 feet of development in shafts, tunnels, and levels, exposing veins varying from 20 to 53 feet wide, mineral-bearing throughout; and ore averages $50 silver per ton." The Mint report for 1890 gives the output of the mine for that year as follows: gold $80, silver (coinage value) $10,068. Smaller amounts are recorded for earlier years.

REVENUE MINE

In 1912 this mine was worked through a shaft 100 feet deep, on the pitch, while a drift on the 100-foot level was being driven northward to give an outlet on the hillside. For the first 100 feet from the surface the vein dips 60° to 75° westward and strikes about N. 28° W. When the mine was visited the drift on the 100-foot level had been driven about 180 feet, and through this distance the vein had an average width of four or five feet. In the upper workings the main vein runs about three to six feet in width. A second vein, having a maximum width of about 20 inches, meets the main vein 20 feet north of the shaft. Drifts, from about 50 feet to more than 100 feet in length, have been run on the main vein at depths of 35, 50, and 85 feet. Ore was stoped from the 35-foot level to the surface, and a small amount was mined on each level.

The vein, which is reported to have been traced at the surface a distance of 1,400 feet, is well defined. The walls are hornblende-bearing gneiss or schist. Though the rock makes a good foot wall, the vein seems to grade into the hanging wall, the latter being penetrated by numerous veinlets of quartz. The vein filling is principally quartz, but considerable pyrite is associated with the quartz on the 100-foot level. Some of the pyrite has been oxidized to limonite on this level, while nearer the surface limonite is more abundant. Part of the ore of the oxidized zone is copper-stained. The ore on the 100-foot level is said to average nearly $13 per ton in gold, while that stoped near the surface ran about $24 per ton. Picked samples carry much higher values. Free gold in considerable quantity can be panned from the ore of the oxidized zone.

The mine is equipped with a steam hoist, and the ore is carried by gravity over an aerial tram to the amalgamating and concentrating mill 800 feet below.

ROOSEVELT

The Brandt Independent Mining Company owns a large number of claims south of Quartz Creek, and mostly in the Box Canyon mining district. Of these, only the Roosevelt—a group of seven or more claims—lie within the area mapped.

On the Roosevelt claims a wide quartz vein, striking eastward, has been opened by several short tunnels. The vein, where it has been prospected, is mainly in basic diorite. The quartz on the dumps is much stained with limonite and malachite. Mr. A. P. Nelson, president of the company owning this property, reports good assay values from samples collected here.

A tunnel, driven in granite and diorite to develop this property, had, in September, 1914, reached a length of 1,700 feet. A hydro-electric plant was being built at the time mentioned, and was reported completed and in operation in August, 1915.

CARBONATE KING

The Carbonate King property includes several claims near the source of Alder Creek. The principal workings, which are in limestone, include a gently pitching incline about 200 feet long, a crosscut of about 150 feet from the bottom of the incline, and a drift about 30 feet in length.

The limestone has been considerably fractured, and many of the fractures were subsequently filled with coarsely crystallized calcite. When the property was visited in 1912, about a ton of good calamine had been sorted on the ore platform. This evidently came from the drift mentioned, where veins of ore one inch to one foot in thickness could still be seen in the walls. A sample of the calamine, assayed by Mr. Watts, carried 49.7 per cent zinc, lacking only about 4.5 per cent of being pure calamine. The sample selected was perhaps better than the average, though not so good as some specimens seen.

BORNITE

A caved prospect on Henry Mountain showed in 1911 that a vein containing bornite and malachite had been opened many years ago. The same vein has recently been reprospected near the surface; and in 1914 a tunnel had been started to cut the vein at a greater depth.

When seen by the writer the recent surface workings were caved, but material on the dump indicated that there was either a filled fissure at least one foot wide, or bornite had been deposited in fractures in pegmatitic quartz. Specimens of a good quality of bornite, associated with quartz, were seen. At the surface malachite impregnates the schist to a distance of 2 feet or more. Blocks on the dump indicate a good quality of workable ore at least 2 feet wide. The talus that covers the slope in the direction of strike of the vein prevents one's forming an intelligent opinion, without further prospecting, of the linear and vertical extent of the vein. Features favorable to a workable ore body are the large body of granite intrusive in the schist and the abundance of malachite at the surface of pegmatite bordering this granite not far northeast of Henry Mountain.

OTHER MINES FORMERLY PRODUCTIVE

In addition to the mines and prospects described there are many claims that have produced ore, mostly in the eighties. Among those credited with production are the following: Bertha, Buckeye Chief (formerly Sultan and Sultana), Calumet, Chicago, Climax, Dodson, Double Header, Eagle, Golden Currie, Golden Eagle, Golden Fleece, Gold Monument, Ida May, Idoline, Kansas City, Last Delusion, Leona, Lillie Dell, Little Dora, Manitou, Montreal, Ontario, Sheol, Soft Snap, Teller, Tidal Wave, Toronto, Wall Street, West Point, and Whig.

On some of these claims as, for example, the Teller and Whig, extensive development work has been done. Many of the claims mentioned have not been worked for a number of years past. Not a few are probably now owned by the larger companies, and have been developed through the tunnels opening on Gold Creek.

PLACER MINING

During the first years of mining in this district considerable ground was successfully washed for placer gold in Jones Gulch and at Dutch Flats. A small quantity of gold was obtained from placers in Spring Gulch.

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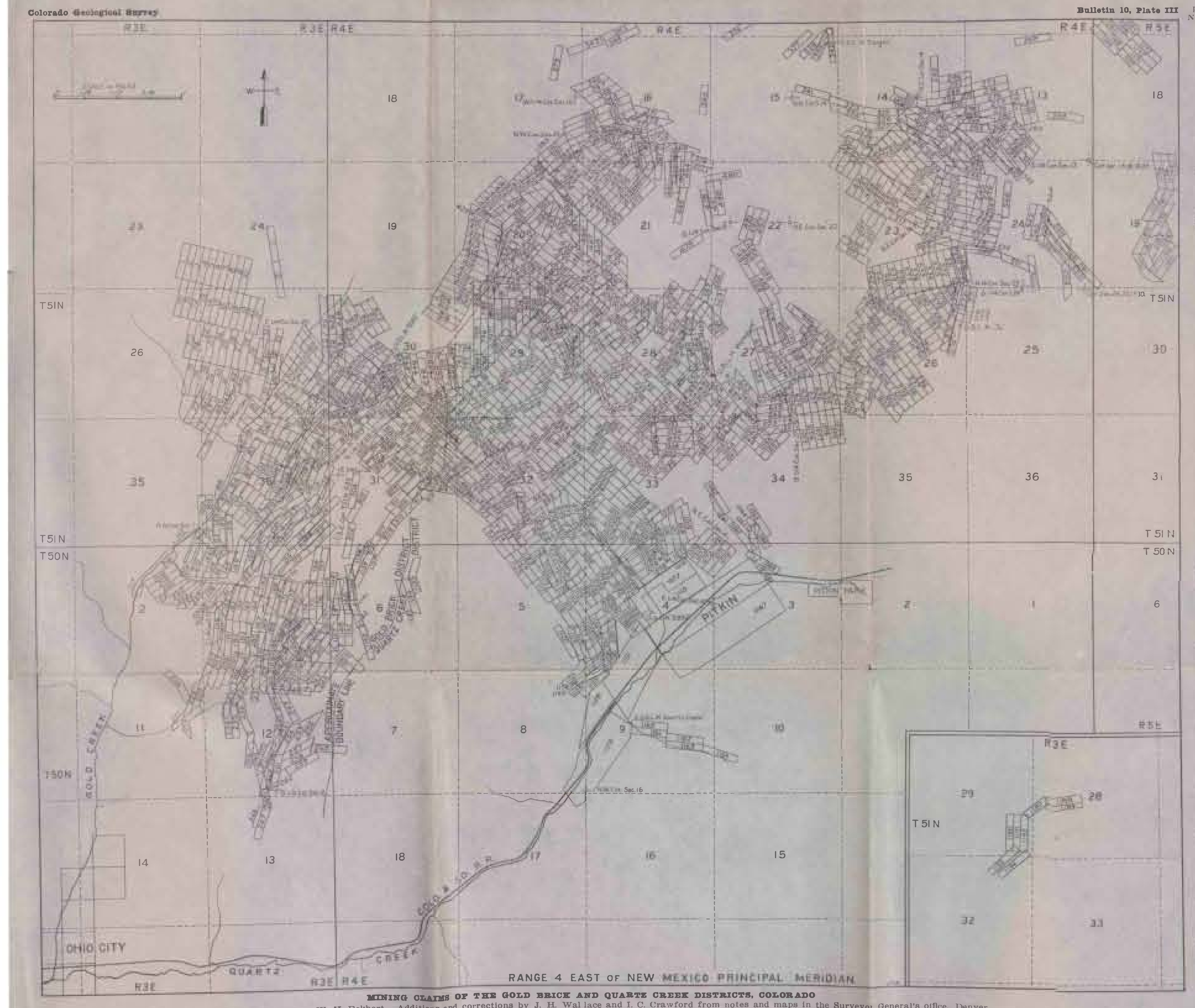

MINING CLAIMS OF THE GOLD BRICK AND QUARTZ CREEK DISTRICTS, COLORADO

From map made by W. H. Eckbert. Additions and corrections by J. H. Wallace and I. C. Crawford from notes and maps in the Surveyor General's office, Denver.

Index Number	Survey Number	
		Tp. 51 N., Range 3 E., Sec. 23
1	18550	Morning Star No 4
2	18550	Morning Star No 5
3	18550	Morning Star No 6
		Tp. 51 N., Range 3 E., Sec. 24
4	18550	Morning Star No. [illegible]
5	18550	Morning Star No. 8
6	18550	Morning Star No. 9
7	18550	Morning Star No. 10
8	18550	Morning Star No. 11
9	18550	Morning Star No. 12
10	18550	Morning Star No. 13
11	1580	Chronicle No. 2
12	6499	Chronicle
		Tp. 51 N., Range 3 E., Sec. 25
13	18550	Peerless No. 15
14	18550	Peerless No. 13
15	18550	Peerless No. 11
16	18550	Peerless No. 28
17	18550	Peerless No. 27
18	18550	Peerless No. 26
19	18550	Peerless No. 25
20	18550	Peerless No. 24
21	18550	Peerless No. 23
22	18550	Peerless No. 10
23	18323	Peerless No. 9
24	18323	Peerless No. 8
25	18323	Peerless No. 7
26	18323	Peerless No. 6
27	18323	Peerless No. 5
28	18323	Peerless No. 4
29	18323	Peerless No. 3
30	18323	Peerless No. 2
31	18323	Peerless No. 1
32	18323	Wilson
33	18323	Gold Dollar
34	19580	Gold Dollar
35	15656	Gold Link No [illegible]
36	18323	Sunny Side
37	18323	Denver City
38	18550	Fairbanks No. 7
39	18550	Fairbanks No. 6
40	18550	Fairbanks No. 5
41	18550	Fairbanks No. 4
42	18550	Boston No. 3
43	18323	Fairbanks No. 3
44	18323	Fairbanks No. 2
45	18323	Fairbanks No. 1
46	18550	Peerless No. 32
47	18550	Peerless No. 31
48	18550	Peerless No. 30
49	18550	Boston No. 2
50	18427	Chrysolite No. 5
51	18427	Mutual No. 1
52	18427	Mutual No. 2
53	18427	Mutual No. 3
54	18427	Mutual No. 4
55	18427	Mutual No. 5
56	18287	Bellzora No. 5
57		New Bassick
58	15546	Monte Vista No 2
59	15546	Monte Vista
60	18287	Olmutz
61	15656	Gold Link No. 10
62	15656	Gold Link No. 7
63	15656	Gold Link No 6
64	15656	Gold Link No 5
65	15656	Gold Link No. 4
66	15656	Gold Link No. 3
67	15577	Double Header
68	15656	Gold Link No. 2
69		Gold Band No. 6
		Tp. 51 N. Range 3 E., Sec. 26
70	18550	Peerless No. 21
71	18550	Peerless No. 19
72	18550	Peerless No. 17
73	18550	Peerless No. 14
74	18550	Peerless No. 12
75	18550	Fairbanks No. 9
76	18550	Fairbanks No. 8
77	18550	Bowlder
		Tp. 51 N., Range 3 E., Sec. 36
78	18550	Boston No. 1
79		Gold Band No. 10
80		Gold Band No. 11
81		Gold Band No. 12
82	1621 B	Mill Site
83	2527	Boss
84	2526	Sterling
	17278	Gold Brick No. 1
85	2594 A	Legal Tender
	17278	Gold Brick No. [illegible]
86	17947	Jessie
87	17278	Gold Point
88	9219 B	Mono M. S.
89	17482	New Century
90	7542	Venango
91		Gold Band No. 5
92		Gold Band No. 9
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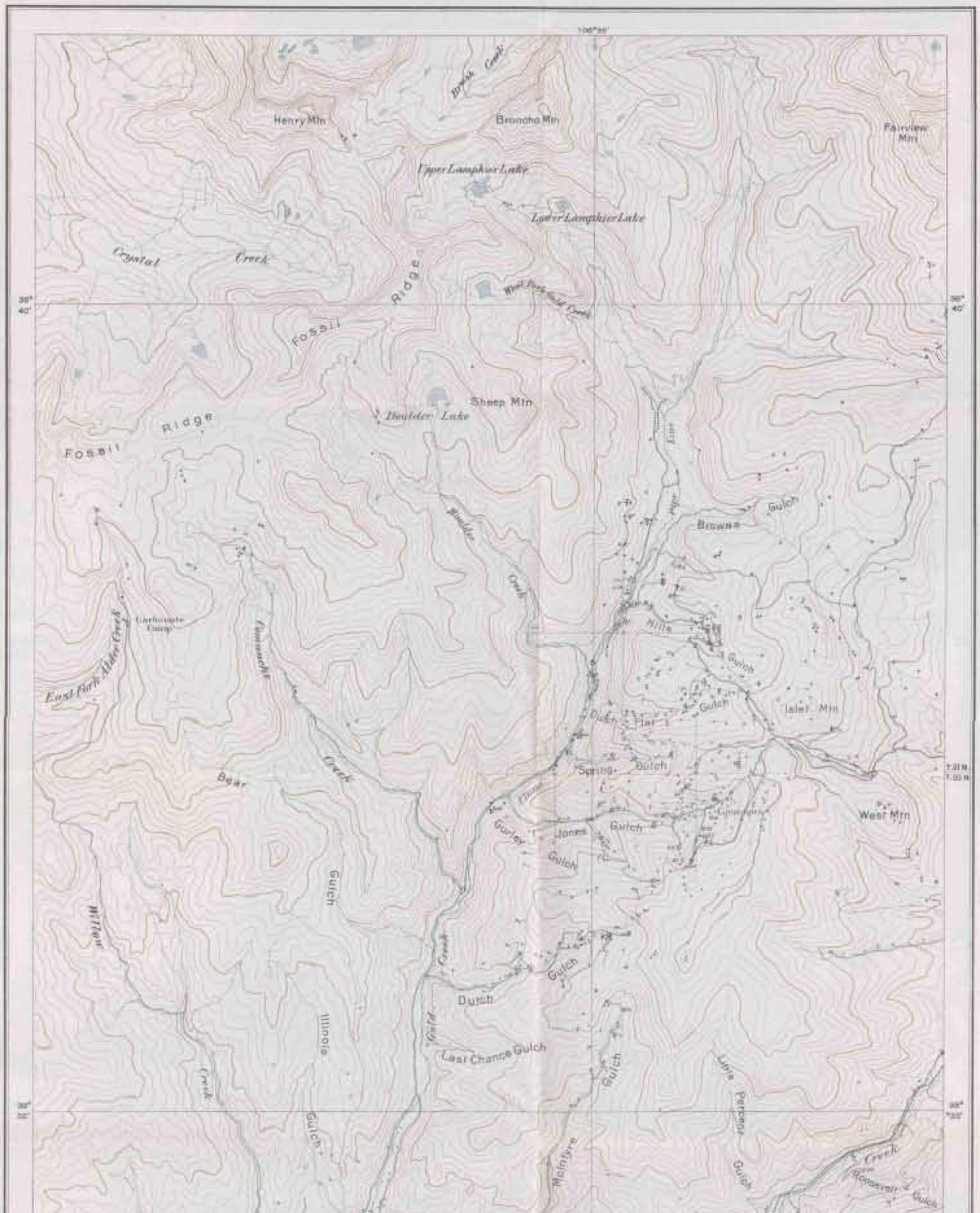
1193		Big Jim
1194		Grizzly King



LEGEND

Mine Prospect

Land corner known

MINES AND PROSPECTS

1 Carbonate King
2 Bornite
3 Chronicle
4 Sandy Hook tunnel
5 Sandy Hook (McCarty tunnel)
6 Sandy Hook
7 Denver City
8 Mutual
9 Bassick
10 Monte Vista
11 Gold Links
12 Sacramento
13 Sacramento
14 Sacramento
15 Silver Islet
16 Teller
17 Maggie Mitchell
18 Whig
19 Hilltop
20 Hilltop
21 Grey Eagle
22 Bertha
23 Buckeye Chief
24 Grand Prize
25 Chloride
26 Chloride-Grand Prize tunnel
27 Granite Mountain
28 Mono
29 Chicago
30 Lucille
31 Raymond
32 Raymond
33 Carter
34 Volunteer
35 Cortland shaft
36 Cortland tunnel No. 4
37 Revenue
38 Roosevelt tunnel
39 Golden Islet

Topography by R. C. Coffin, R. G. Coffin, G. B. Warner, A. W. Lauer. Surveyed in 1911-12.

ROCKY MOUNTAIN BANK NOTE CO

TOPOGRAPHIC MAP OF THE GOLD BRICK MINING DISTRICT, COLORADO

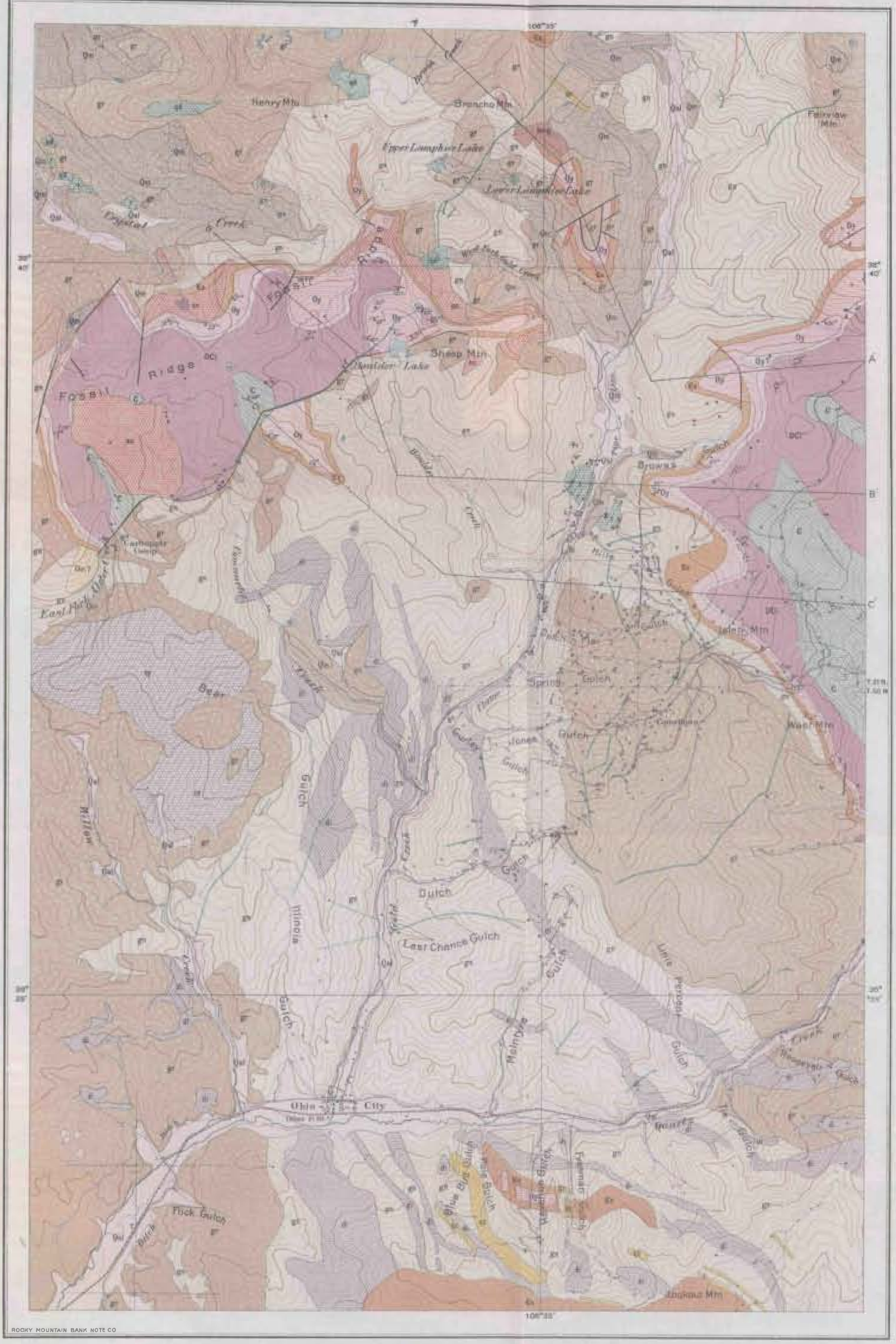
Scale $\frac{1}{42000}$, approximately 1½ inches to 1 mile

Miles

Kilometers

Contour interval 100 feet
Datum is mean sea level

COLORADO GEOLOGICAL SURVEY
R. D. GEORGE, DIRECTOR



Topography by
R. C. Coffin, R. G. Coffin,
G. B. Warner, A. W. Lauer.
Surveyed in 1911-12.

GEOLOGIC MAP OF THE GOLD BRICK MINING DISTRICT, COLORADO

Geology by
R. D. Crawford, P. G. Worcester,
R. C. Coffin, R. G. Coffin, R. M. Butters
Surveyed in 1911-12.

Horizontal and vertical scale $\frac{1}{42000}$, approximately 1½ inches to 1 mile

½ 0 1 2 3 Miles

1 Kilometers

Contour interval 100 feet
Datum is mean sea level