PRELIMINARY REPORT ON THE ECONOMIC GEOLOGY OF GILPIN COUNTY, COLORADO.

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INTRODUCTION.

The following brief account of the economic geology of Gilpin County and adjacent portions of Clear Creek and Boulder counties, Colo., summarizes the more important results of an exhaustive geologic study of the region. The final report, which will appear as a professional paper of the United States Geological Survey, is voluminous, and as its publication will consume much time it appears desirable to publish this summary to meet in part the numerous demands for information concerning this important mining district.

The area considered lies 30 to 35 miles west and northwest of Denver, in the heart of the Front Range of the Rocky Mountains. It is the oldest lode-mining region in Colorado, and its discovery in 1859 was the occasion of a " rush " second only in magnitude and consequences to that caused by the California discoveries of 1849. The area includes the productive portions of Gilpin County and small adjacent parts of Boulder and Clear Creek counties, all within the regions shown on the Central City topographic sheet of the United States Geological Survey. The country is mountainous and of moderate humidity. The principal mining centers are, in Gilpin County, Central City, Blackhawk, Nevadaville, Russell Gulch, Perigo, and Apex; in Clear Creek County, Idaho Springs, Gilson, Alice, Dumont, and Lawson; in Boulder County, Caribou and Eldora.

GENERAL GEOLOGY.

The entire area is underlain by the body of pre-Cambrian rocks that forms the core of the Front Range. Probably in early Tertiary time igneous rocks of many varieties were intruded as dikes or stocks into the pre-Cambrian rocks; these intrusives are the " porphyries " of the miners. Surface deposits formed by glaciers or streams are the only other formations present.

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[1] Mr. Charles W. Henderson assisted in a part of the field work.

PRE-CAMBRIAN ROCKS.

The essential characters of the pre-Cambrian formations are shown in tabular form below, the youngest at the top, the oldest below:

Pre-Cambrian rocks of Central City quadrangle, Colo.

Igneous rocks.	*Silver Plume granite:* Medium-grained biotite granite with coarser pegmatitic facies.	Little or not at all dynamometamorphosed.
	Quartz diorite: Medium grained, locally grading into hornblendite.	
	Granite gneiss: Fine to medium grained, somewhat gneissic granite with coarse-grained pegmatitic facies.	Moderately dynamometamorphosed.
Sedimentary rocks.	*Idaho Springs formation:* Mostly quartz-biotite and biotite-sillimanite schist, with some hornblende schist and lime-silicate rock.	Highly dynamometamorphosed.

The more important characteristics of these formations are briefly described below.

IDAHO SPRINGS FORMATION.

The Idaho Springs formation, first defined by Ball,[1] underlies fully half of the eastern portion of the Central City quadrangle. It is also widely distributed to the east, in the Blackhawk quadrangle, and to the south, in the Georgetown quadrangle. As its commoner rock types are somewhat less resistant to erosion than most other rocks of the region it forms few high peaks or ridges, and for this reason it is a fair inference that the formation is not so widespread in the high western portion of the quadrangle, not here mapped, as in the eastern portion.

Over certain areas, as for example between Nevadaville and Mount Pisgah, the formation is rather free from intrusive igneous rocks; but in most localities igneous rocks are associated with it in great abundance and in very intimate and irregular fashion.

The predominant rocks of the Idaho Springs formation are light to dark gray quartz-biotite schists, in places carrying some hornblende or muscovite. With these are associated lesser amounts of biotite-sillimanite schist, quartzitic gneiss, dark-green hornblende schist and gneiss, and lime-silicate rocks that represent metamorphosed limestones, and in a few places rocks that are supposed to be metamorphosed conglomerates are found. These rocks are interbanded, show transitional varieties, and are clearly integral parts of one formation. The less common types occur mostly as lens-shaped

[1] Ball, S. H., Geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

masses and not as continuous bands that might serve as indicators of structure.

Throughout most of the formation bedding planes have been entirely obliterated by the development of schistose structure, the biotite and biotite-sillimanite schists in particular being highly foliated. On the other hand, certain bands of quartzitic schist that in some places persist with fairly uniform width for several hundred feet are interpreted to represent beds, originally more sandy than their neighbors, that have retained in part their original form because the constituents for the development of platy minerals during metamorphism were scarce.

The general strike of the foliation is, in some parts of the quadrangle, fairly uniform over a number of square miles, but in most places the schists have been so disturbed by numerous intrusions of igneous rocks that all conceivable inclinations can be observed within a single square mile, and faulting has produced further irregularities. The foliation exhibits no broad parallelism with the axis of the range.

The Idaho Springs schists and lime-silicate rocks are believed to have been formed by the general dynamic metamorphism and local igneous metamorphism of a thick series of sedimentary rocks.

GRANITE GNEISS.

The granite gneisses of this area have acquired a gneissic structure through dynamic metamorphism. Their essential minerals, like those of the massive granites, are quartz, alkali feldspar, and either muscovite or biotite.

The granite gneiss is comparatively rare in the northern part of the area mapped but underlies nearly half of the central and southern portions. Its areas, though of irregular outline, are commonly elongate in a northeasterly direction, parallel to the dominant trend of the inclosing Idaho Springs schists. Some areas are 4 to 5 miles long and 2 to 3 miles across, but most of these large masses inclose small areas of the Idaho Springs formation. Excellent exposures of the granite gneiss are numerous on the surface and in the mines near Central City and along the lower course of Fall River.

The granite gneiss is believed to be a granitic intrusive rock that has received a foliated structure as a result of dynamic metamorphism subsequent to its intrusion. Its intrusive character is attested by occasional offshoots from the gneiss masses that penetrate the Idaho Springs schists, transgressing their foliation, by angular schist fragments inclosed by the granite gneiss, and by contact-metamorphic effects produced in rocks of the Idaho Springs formation inclosed by or bordering on masses of granite gneiss.

The granite gneiss is a part of the pre-Cambrian axis of the Front Range. Its structural relations and its degree of metamorphism indicate that it is intermediate in age between the oldest and the youngest of the pre-Cambrian rocks. It is distinctly younger than the oldest pre-Cambrian formation, the Idaho Springs formation, which it intrudes. It is evident, moreover, that the Idaho Springs formation was schistose prior to the intrusion of the granite gneiss magma and that the magma in many places followed this schistosity as the direction of easiest intrusion. At least one important period of dynamic metamorphism intervened, therefore, between the deposition of the sediments of the Idaho Springs formation and the intrusion of the granite gneiss magma. On the other hand, the granite gneiss is itself intruded by granite pegmatite and massive granite of later age.

QUARTZ DIORITE AND ASSOCIATED HORNBLENDITE.

Massive to slightly gneissic coarse-grained rocks varying from quartz diorites to hornblendites in mineral composition are found principally in the central and southern parts of the area surveyed. The largest body extends from a point 1¼ miles east of Yankee northeastward to Montana Mountain and Pine Creek, and its width for most of this distance is nearly half a mile. Most of the other bodies form broad dikes whose trend is northeast, parallel to the prevailing trend of the foliation in the inclosing schists and gneisses. In the northern part of the area surveyed quartz diorite has been noted only in two small patches north of Nederland.

The quartz diorite and its associated lighter and darker colored rocks are intrusive igneous rocks, probably of pre-Cambrian age. They were intruded subsequent to the development of most of the foliation in the Idaho Springs formation but before the intrusion of the Silver Plume granite and its associated pegmatite. The relation of the quartz diorite to the granite gneiss, though far from clear, suggests that the two rocks are of nearly the same age and possibly came from a common magmatic source. An alternative hypothesis, suggested by Ball,[1] is that the quartz diorites and hornblendites are derived from the same magmatic source as certain pre-Cambrian quartz monzonites that occupy large areas in the Georgetown quadrangle but are not exposed within the surveyed parts of the Central City quadrangle.

GRANITE PEGMATITE.

Under the name granite pegmatite are included rocks of coarse and usually irregular texture, containing the same minerals that are found in normal granites. The principal constituents are potash feldspar,

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[1] Ball, S. H., op. cit., p. 56.

quartz, biotite, and muscovite, but many other minerals are present in subordinate amounts.

Granite pegmatite in masses too small to map is abundant throughout most of the area mapped as Idaho Springs formation. Most of these small intrusions have the form of long, narrow lenses, or pinching and swelling dikes, lying parallel to the foliation of the schists or cutting the foliation at small angles. Other pegmatite masses are exceedingly irregular and may transect the schist foliation in various directions and even inclose angular fragments of schist. In many places the pegmatite magma penetrated the schist so intimately that pegmatite and schist form an injection gneiss, and locally isolated "eyes" of pegmatite were developed; these show no evidence of strain and can not be regarded as pegmatite fragments isolated as a result of shearing.

The granite pegmatites of the Central City quadrangle are believed to have been derived in part from the granite gneiss magma and in part from the Silver Plume granite magma. As the pegmatites derived from each source are similar in mineral character it is possible to distinguish them only in the relatively few places where they can be traced into bodies of granite gneiss or granite. The relative importance of the two magmas as sources of pegmatites can not be estimated, but it seems probable from the areal distribution of granite gneiss and granite that the pegmatite of the southeastern part of the quadrangle came mainly from the granite gneiss magma and that of the northeast part of the quadrangle came mainly from the Silver Plume granite magma. As already stated, the granite gneiss and the Silver Plume granite, though probably of widely diverse ages, are both believed to be pre-Cambrian. So far as observed, the Tertiary (?) "porphyry" magmas yielded no pegmatitic rocks.

SILVER PLUME GRANITE.

The name Silver Plume granite was applied by Ball to a medium-grained, usually porphyritic biotite granite forming numerous stocks and dikes in the vicinity of Silver Plume and Georgetown. In the present report all the granite of the quadrangle that is distinctly younger than the granite gneiss is classed under this heading, although there is some question whether all of it is the precise equivalent of the granite of the type locality near Silver Plume.

The Silver Plume granite is widely distributed through all except the southeastern portion of the quadrangle. It forms irregular stocks, commonly more or less elongate parallel to the prevailing trend of the foliation in the schist of the Idaho Springs formation or the granite gneiss. The largest body, just northeast of Caribou, is about 3 miles across.

The Silver Plume granite is intrusive into most of the pre-Cambrian rocks of the quadrangle. The only rocks observed to cut the granite are the "porphyries," of probable Tertiary age, and a few dikes of pegmatite which probably came from the same magmatic source as the granite itself. The Silver Plume granite is believed to be pre-Cambrian, and with the exception of its own pegmatitic phases it is the youngest of the pre-Cambrian rocks of the quadrangle. The possibility of a Paleozoic age for this granite can not be excluded on the basis of any evidence found within this quadrangle, but where Paleozoic rocks are exposed on the flanks of the Front Range no granites intrusive in them have been noted.

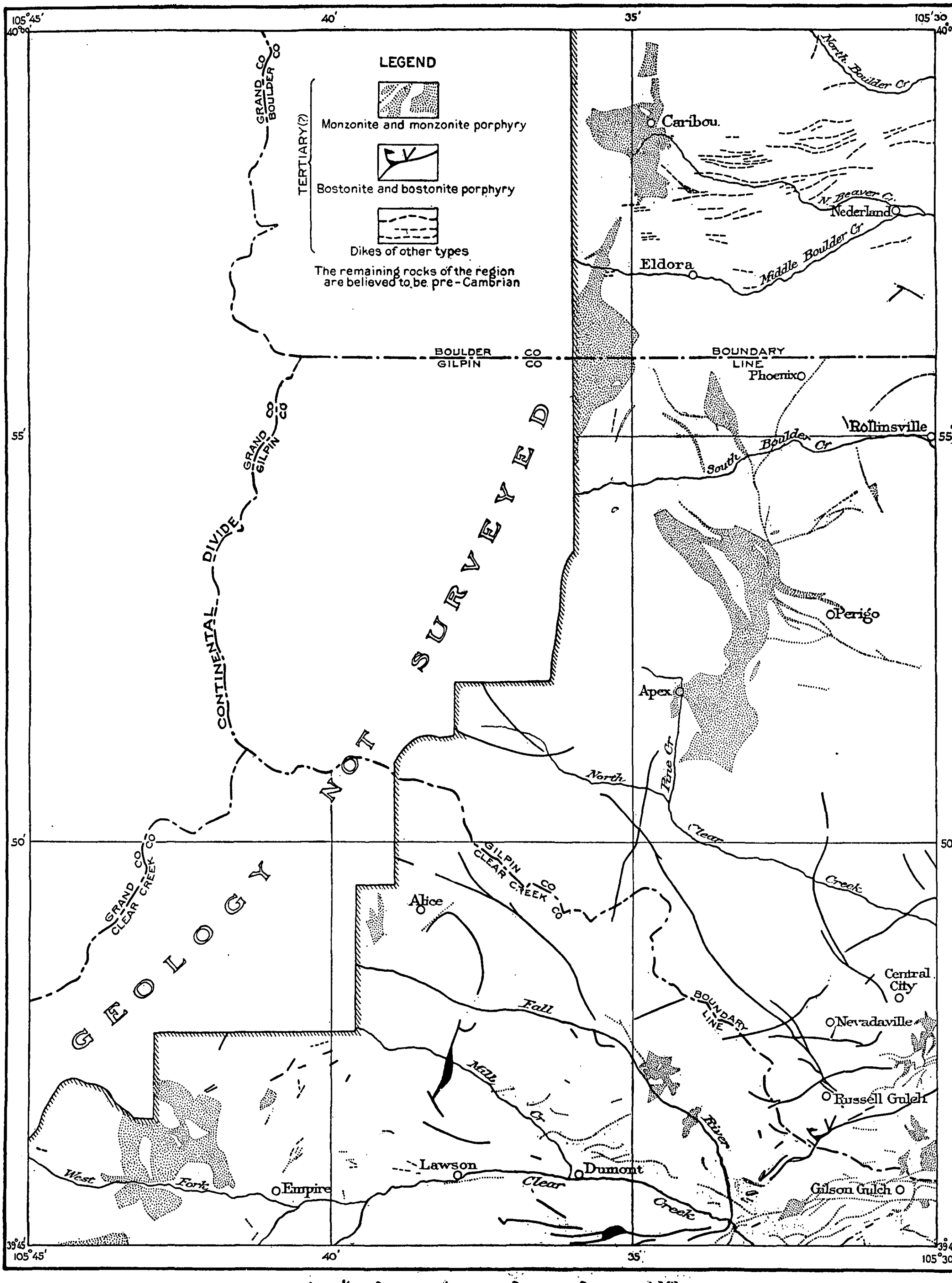
TERTIARY (?) INTRUSIVE ROCKS.

PRINCIPAL TYPES.

Throughout all parts of the area surveyed igneous rocks, intrusive in the pre-Cambrian formations, are of common occurrence. These intrusives constitute irregular stocks and dikes, whose form and distribution are shown on Plate IX. The commonest rock types are monzonites and related quartz monzonites, in large part of porphyritic texture. These rocks make up practically the whole mass of the larger stocks and many of the dikes, and in quantity they far exceed all other types among the Tertiary (?) intrusives. The remaining types occur as dikes and small stocks and lenses and to a lesser extent as irregular masses within monzonite stocks. The best examples of these irregular masses are the titaniferous iron ores and associated gabbros, peridotites, etc., near Caribou, which are clearly differentiation products within a monzonite magma. The dikes and small stocks and lenses are represented by the bostonites of the southern part of the quadrangle and the andesites, diorites, and basalts of the northeastern part of the quadrangle. Although many of these dike rocks differ greatly in mineral character from the quartz monzonites, it is thought probable that most of them had a common magmatic source and are of essentially the same age. Their differences are attributed to magmatic differentiation at considerable depth prior to intrusion into their present positions.

As the monzonitic rocks constitute most of the stocks as well as many of the dikes, their total volume is many times the combined volume of all other types. It is probable, therefore, that the parent magma from which the various rock types were derived, through differentiation, had very nearly the average composition of the large monzonite stocks.

The two most abundant types among the Tertiary intrusives may be briefly described. Their distribution is shown on Plate IX.



SKETCH MAP OF CENTRAL CITY QUADRANGLE, COLORADO, SHOWING DISTRIBUTION OF TERTIARY(?) INTRUSIVE ROCKS.

QUARTZ MONZONITE AND QUARTZ MONZONITE PORPHYRY.

The quartz monzonites of the Central City quadrangle contain orthoclase feldspar, calcic plagioclase feldspar, some quartz, and usually some iron-bearing minerals. There are great variations in the proportions of the minerals, in the coarseness of the grains, and in the degree to which phenocrysts are developed. In many localities iron-bearing minerals are not conspicuous, but in certain places they may be present in amounts up to 30 or 40 per cent by volume and give to the rock a dark-gray color. In the porphyritic varieties the phenocrysts may be wholly feldspar, or there may also be phenocrysts of quartz or of iron-bearing minerals. The phenocrysts may be small or large, ranging from 1 millimeter to 3 centimeters, and may be all of the same order of magnitude or of heterogeneous sizes. The groundmass appears structureless (aphanitic) to the unaided eye and in fresh specimens is light gray to purplish gray. In the nonporphyritic varieties the texture may approach porphyritic (porphyroid) or, more rarely, may be rather evenly granular. A few dikes are coarsely porphyritic at the center and more finely porphyritic or massive at their borders. Many varieties are usually present within the same monzonite stock, and even a single narrow dike may show considerable variations in character along its length. The monzonites are usually massive; only in a few places do they show a slight banding attributable to flowing movements during crystallization.

Quartz monzonites and monzonite porphyries are present in nearly all parts of the area surveyed. The largest masses are the stocks near Apex, Ute Mountain, and Caribou. Dikes are particularly abundant in the vicinity of Idaho Springs. The details of distribution are fully shown on the map (Pl. IX).

BOSTONITE AND BOSTONITE PORPHYRY.

The bostonites of the Central City quadrangle are gray to lilac-colored or reddish-brown, very fine grained (microcrystalline) rocks, composed predominantly of alkali feldspar with only small amounts of quartz. Varieties with phenocrysts of alkali or alkali-calcic feldspar or of pyroxene, or both, are termed bostonite porphyry. The bostonites and bostonite porphyries are confined mainly to those parts of the surveyed area lying southeast of Mammoth Gulch and east of Empire. They occur mainly as dikes, which in a few places expand into lens-shaped masses one-eighth of a mile or so across. Some of the dikes are of extraordinary lengths, one being traceable continuously from the Topeka mine, near Russell Gulch, northwestward for 4½ miles. The distribution of the bostonite dikes between the camps of Russell Gulch and Nevadaville is noteworthy, for they radiate from a small bostonite area near the Topeka mine. Expansions of the dikes into narrow stocks occur 1 mile southeast of Dumont and $1\frac{1}{2}$ miles north of Lawson.

Though the bostonite porphyries are not always distinguishable without microscopic study from certain monzonite porphyries, most of them can be readily recognized because of their pinkish, lilac, or reddish-brown body or groundmass through which are scattered pearl-gray or salmon-colored phenocrysts of feldspar, commonly under 5 millimeters in length, though occasionally as long as 1 or even 2 centimeters. Some varieties contain green prisms of pyroxene or its alteration products as much as 5 millimeters in length.

The pyroxene-free bostonite porphyries are not readily differentiated, without the aid of the microscope, from certain monzonite porphyries of the region between Apex, Perigo, and Phoenix, which have a pinkish groundmass, but microscopic examination of the monzonites shows that the groundmass is granular rather than trachytic, as in the bostonites. In most of the bostonite porphyries the phenocrysts are widely scattered, and many of them show rhombic outlines. The nonporphyritic bostonites, if fresh, are usually recognizable by their lilac or reddish-brown color, but if altered by surface weathering or by mineralizing solution they are usually bleached buff and can not then be distinguished, without microscopic examination, from fine-grained monzonites.

OTHER TERTIARY (?) INTRUSIVE ROCKS.

In the vicinity of Caribou there occur within monzonite stocks small bodies of dark-colored rocks, including iron ores, which have clearly formed by processes of differentiation from the monzonite magma. These rocks are further mentioned on page 313 in the discussion of the titaniferous iron ores.

The region between Caribou, Nederland, and Phoenix is characterized by the presence of a profusion of dikes, having a prevailing easterly trend, of types not found elsewhere in the quadrangle. They include hornblende monzonite porphyries, hornblende and biotite andesites, and hornblende and biotite diorites. Many of the diorites are very dark. These various dikes are not wholly contemporaneous, for at a number of places diorite dikes were observed to cut those of andesite. Nevertheless, it seems probable that the age differences are not very great and that all types were derived from a common parent magma of monzonitic composition. These dikes appear to take the place, in the Nederland region, of the monzonite dikes so common in other parts of the quadrangle.

The geologic relations within the Central City and Georgetown quadrangles indicate merely that the "porphyries" are younger than the pre-Cambrian rocks, which they cut, and are, with a very few exceptions, older than the ore deposits. In neighboring parts of Colorado, however, similar "porphyries" are in contact with sediments of determinable age. The evidence from these adjacent districts points to a Tertiary age for these intrusive rocks.

STRUCTURE.

The most important structural characteristic of the region is the intricate manner in which the igneous rocks, ranging from pre-Cambrian to Tertiary (?) in age, have been intruded into the sedimentary Idaho Springs formation and into each other. The intrusives range in size from mere threads between schist folia to stocks several miles across. Dikes are particularly abundant, and a few of them are traceable continuously for over 5 miles. Many of the intrusives are lenticular in form, with their greatest dimensions parallel to the prevailing foliation of the inclosing rocks; others are extremely irregular.

Purely dynamic processes have also played a part in the structural history, their principal effect being the development at great depths of foliation in the older pre-Cambrian rocks. During much later periods at shallower depths faulting took place. Some of the faults were formed prior to or contemporaneous with the intrusion of the Tertiary igneous rocks; others were formed soon after these intrusions and became the sites of ore deposition; and still others were formed subsequent to the mineralization and displaced the ore bodies. Faulting may still be in progress. Joints are numerous in the more rigid rocks and commonly parallel one or more of the directions of faulting.

ECONOMIC GEOLOGY.

ORES GROUPED BY PREDOMINANT METAL VALUES.

The ores of Gilpin County and adjacent areas here described may be grouped, according to the metals which give them their predominant value, into five classes—(1) gold-silver ores, which constitute the main economic resource of the region; (2) uranium ores, highly localized but of much interest as a source of radium; (3) tungsten ores, which form the basis of the tungsten industry of Boulder County, the largest producing center for this metal in the United States; (4) copper ores, poor in precious metals, represented solely by the Evergreen mine, near Apex; (5) titaniferous iron ores of Caribou, Boulder County, which are not commercially valuable.

The region forms part of a broad mineralized belt embracing most of the important mining camps of Colorado.

ORE STRUCTURE.

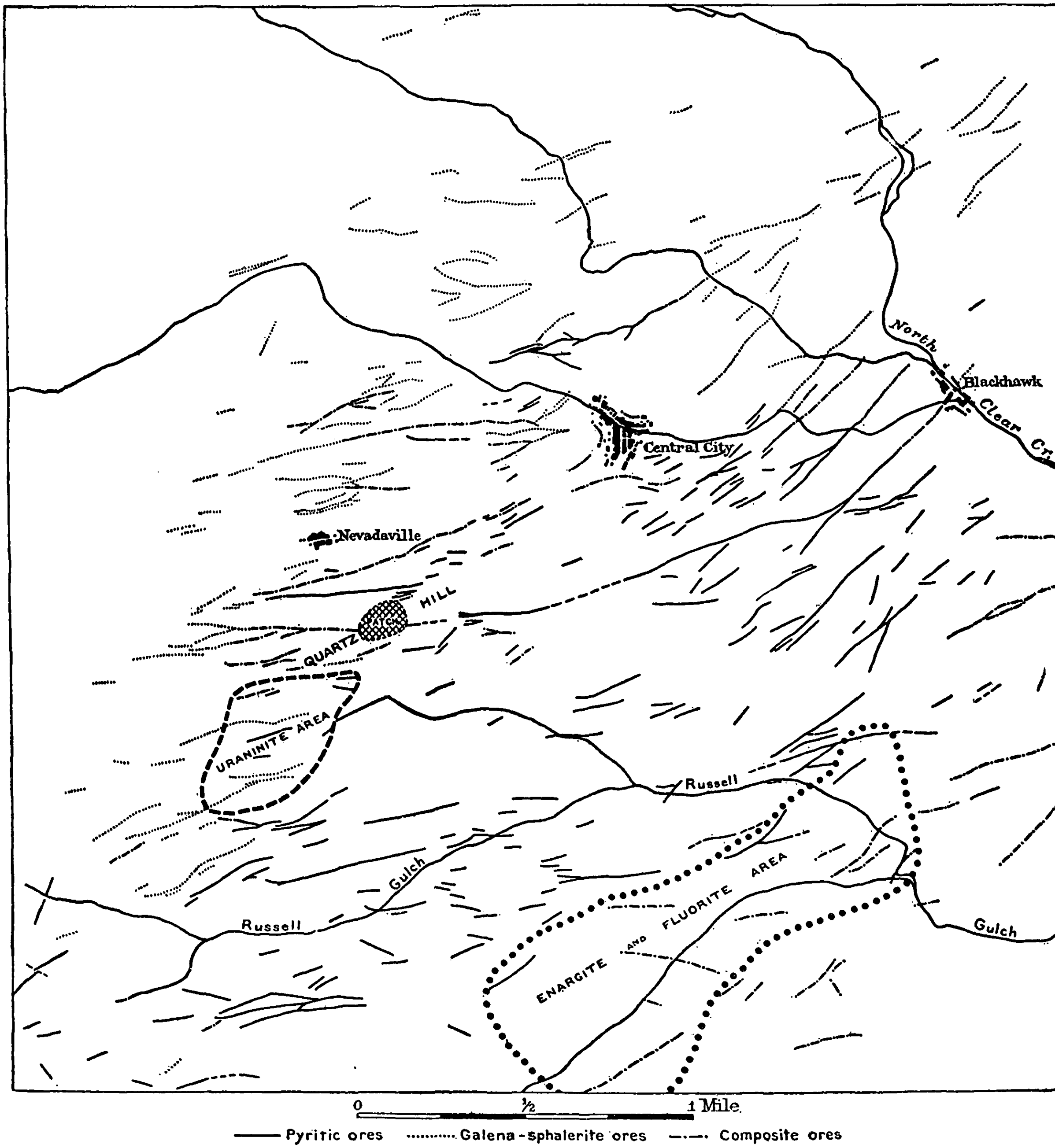
Veins far exceed in abundance and importance all other structural types among the ore deposits of this region. A few large deposits are stockworks, and there are also a few irregular ore bodies formed by magmatic differentiation. Mechanical concentrations are represented by auriferous gravels, now practically worked out.

Veins.—Most of the ore bodies occupy zones of minor faulting and are true veins. These commonly strike between east and N. 45° E., and dip at angles of 60° or more; "flat" veins are rare. Their width is commonly between 1 foot and 5 feet, but telluride-bearing veins as narrow as half an inch or less are worked, and exceptional mineralized zones attain a width of 40 feet. A very few veins are fillings of a single persistent fracture, but most of them are mineralized fracture zones. In many of these zones brecciation has occurred and the spaces between the rock fragments have been filled with metallic minerals. The longest vein noted is the Mammoth, near Central City, which is traceable on the surface almost continuously for 6,000 feet. Few other veins attain half this length. The greatest depth to which a vein has been followed is 2,250 feet along the dip, in the California. While certain veins are without important branches, most of them are elements of a complicated vein network composed of master veins connected by oblique cross veins.

Mineralization along the vein fractures was accomplished by the filling of open spaces and by solution of the rocks and deposition of ore minerals in their place (replacement). In most veins both processes were operative, but their relative importance differs in different veins and in different parts of the same vein. On the whole, replacement has been more important than fissure filling.

Stockworks.—One of the most interesting geologic features of the region is the so-called Patch on Quartz Hill. (See Pl. X.) The Patch may be described as a roughly cylindrical mass of brecciated rock, which is locally well mineralized. Its surface outcrop is oval and about 500 by 800 feet across, and the breccia has been traced downward in mine workings for about 1,600 feet, and may extend much deeper. The brecciated rocks are pre-Cambrian granite gneiss and Tertiary porphyry (bostonite), so that the brecciation is later than the porphyry intrusion. Movement within the Patch has locally been great enough to mingle indiscriminately rock fragments of several different varieties. The brecciation and also the mineralization have, in general, been greatest along the line of several veins of northeasterly trend that enter at one side of the Patch and emerge at the other. The mineralization of the Patch, as of the veins, has been accomplished in part by the filling of open spaces and in part by replacement.

The origin of this peculiar ore body has been the subject of much speculation among the mining men of the region. Detailed evidence of origin will not be given here, but it is entirely clear that the Patch



MAP SHOWING VEINS OF CENTRAL CITY, COLO., AND VICINITY.

breccia was formed by the same general movements that developed the associated vein fractures. Where the Patch now is a number of strong vein fractures approached unusually close to one another, and the movement along them became distributed throughout the intervening rock. The mineralization of the Patch is continuous with that of the veins that enter it and is of the same mineralogic character.

Mineralized breccias similar to the Patch but less extensive occur in the Hubert mine, at Nevadaville, and the Alice and Commercial Union mines, near Alice.

Magmatic segregations.—Within a monzonite stock at Caribou occur four bodies of gabbro and related rock of somewhat rounded outline. The greatest dimension of any of these is about one-fourth mile. Within these gabbro masses in turn occur several small bodies of titaniferous iron ore, some of which are lens-shaped and others wholly irregular. Gradations are traceable from iron ore through gabbro into monzonite, and the ore was unquestionably formed through magmatic differentiation.

The copper minerals of the Evergreen mine, near Apex, occur within dikes of monzonite, where they crystallized at the same time as the silicates of the rock. The ore is apparently a product of magmatic differentiation under localized and unusual conditions. (See pp. 311–312.)

Auriferous gravels.—The Pleistocene and Recent gravels of this area, originally auriferous, were practically worked out many years ago.

GOLD-SILVER ORES.

GENERAL CHARACTER.

The main dependence of the mining industry of Gilpin County is upon auriferous and argentiferous sulphide veins, with a few stockworks. In some of these deposits copper or lead or, more rarely, zinc are abundant enough to be of supplementary value. In most of them gold greatly predominates in value over silver, but in some, usually as a result of downward enrichment in silver, the reverse is the case. Of less though not inconsiderable value are deposits in which the gold and silver occur mainly as tellurides rather than in sulphides. Gold placers may be neglected in the present discussion.

One of the most interesting features of the ore deposits is the mineralogic diversity exhibited by the sulphide ores of gold and silver. This permits them to be classified as (*a*) pyritic ores; (*b*) galena-sphalerite ores; (*c*) composite ores, carrying the minerals of both the other classes. The distribution of the veins of these three classes in the vicinity of Central City is shown on Plate X.

PYRITIC ORES.

The commonest type of gold ores contains pyrite as the predominant sulphide. Chalcopyrite and tennantite are usually present, but always in subordinate amounts. The principal gangue of the ores that are fissure fillings is quartz, but the gangue of the replacement ores is sericitized wall rock. A group of veins, all lying within three-fourths of a mile of the Hazeltine mine, near Russell Gulch (see Pl. X) differ from the commoner pyritic veins in carrying enargite ($3Cu_2S.As_2S_5$) instead of tennantite ($4Cu_2S.As_2S_3$). Fluorite is a constituent of most of these enargite-bearing veins and of a few neighboring veins of the ordinary pyritic type. The enargite and fluorite bearing veins are believed to be merely local variations of the pyritic mineralization, for both enargite and fluorite are contemporaneously intergrown with the typical minerals of the pyritic ores.

Detailed studies of many ore samples show that the pyritic ores are as a rule irregularly massive in texture, and that the characteristic ore minerals were all deposited during the same period of mineralization. It is possible to recognize among them, however, a prevailing sequence analogous to the order of crystallization among the minerals of a massive igneous rock. To epitomize, chalcopyrite, tennantite, and fluorite were deposited in greater abundance in the later than in the earlier stages of the pyritic mineralization, as shown by their tendency to line vugs or to occupy the medial portions of veins. The chemical significance of the order of crystallization may be summarized in the statement that copper, arsenic, antimony, bismuth, and fluorine were deposited mainly in the late stages of the mineralization, whereas iron, sulphur, and silica were deposited throughout the process.

The pyritic ores are the most widely distributed ore type, occurring in practically all parts of the region under discussion. They constitute the entire output of the Saratoga, Pewabic, Old Town, Alice, and many other mines. The metal content of the smelting ore commonly lies within the following limits: Gold, 1 to 3 ounces to the ton; silver, 4 to 8 ounces to the ton; copper, commonly less than 1.5 per cent, but in some ores 15 to 16 per cent. The gold content is commonly highest in the ores that are richest in chalcopyrite.

GALENA-SPHALERITE ORES.

In the ores of the second type the predominant primary sulphides are galena and sphalerite; pyrite is next in abundance, and then chalcopyrite. The principal gangue minerals, where the ores are fissure fillings, are quartz and either siderite or calcite; where the ores are replacements the gangue is sericitized wall rock. Like the pyritic ores, these ores occur principally as veins but subordinately as stockworks. In a few veins of this type situated near the head of Gilson Gulch, northeast of Idaho Springs, rhodochrosite is present. Barite is not uncommon as a subordinate gangue mineral. A distinct sequence in the order of crystallization of the minerals of these ores is much less apparent than in the pyritic ores. Most of the constituents appear to be strictly contemporaneous, but in some ores the crystallization period of resin sphalerite, calcite, siderite, or quartz persisted later than that of the other constituents. The ore texture is irregularly massive, rarely crustified.

The metal content of the galena-sphalerite ores is much more variable than that of the pyritic ores. In some of the ores (those of Red Elephant Hill, near Lawson, and Caribou, for example) the gold content is negligible, and the veins are workable for silver only where the silver content has been augmented by downward enrichment. In others (such as the Topeka, Hubert, and Egyptian) workable amounts of gold occur in the primary ores. In general, for the smelting ores of the galena-sphalerite type, the gold content is between 0.1 and 5.5 ounces and the silver content between 2 and 25 ounces to the ton. A noteworthy exception is the remarkable bonanza ore of the Klondike vein in the Topeka mine, near Central City, which carried free gold in extraordinary amounts. An 88-pound piece when smelted yielded $5,449, largely in gold. This gold was a primary crystallization, being contemporaneously intergrown with the characteristic primary sulphides of the vein. The copper content of the galena-sphalerite ores is usually below the commercial limit of 1.5 per cent and rarely exceeds 10 per cent. Lead ranges from a trace to 55 per cent, and zinc from a trace to 25 per cent. In general the primary ores of this class are poorer in gold and copper and richer in silver than those of the pyritic type.

The galena-sphalerite ores, though widely distributed within the area under discussion, are somewhat less common than the pyritic ores. The mining camps, such as Caribou and Lawson, that have grown up near certain groups of these veins, are classed as silver camps because of the great predominance of that metal in their ores.

COMPOSITE ORES.

The ores to which the term composite is here applied are the result of dual mineralization, first with minerals characteristic of the pyritic ores and later with minerals characteristic of the galena-sphalerite ores. Many of the most important mines of the region, such as the Gunnell and California, have produced ores of this character. Plate XI shows the appearance to the unaided eye and figure 18 the microscopic appearance of typical composite ores. Such relations as are pictured in these illustrations indicate (1) pyritic mineralization, (2) fracturing, and (3) mineralization of the galena-sphalerite type. These relations were noted in many ores in all parts of the region, and it appears certain that they are usual and not exceptional. The reverse relation, of galena-sphalerite ore brecciated and its interspaces filled with pyritic ore, was nowhere noted. In harmony with this relation is the occurrence of minerals characteristic of the galena-sphalerite ore type in vugs in pyritic ore. In many mines two or all of the three types, pyritic, composite, and galena-sphalerite ores, may be present. Veins that near the surface are composite very commonly become pyritic at greater depths, and many veins are composite at one end of their outcrop and pyritic at the other.

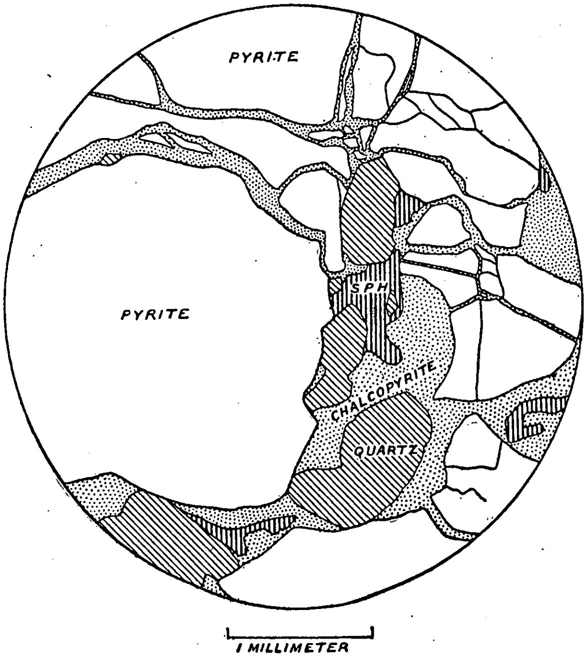
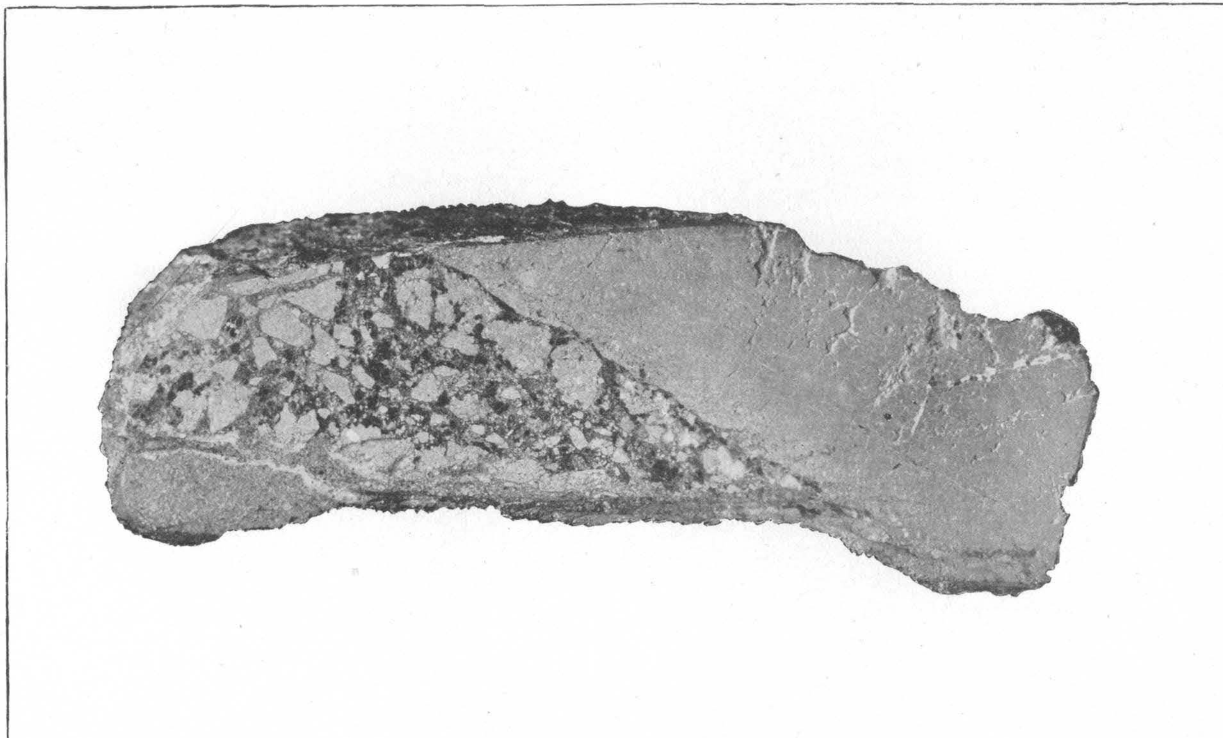


FIGURE 18.—Drawing showing microscopic appearance of polished surface of gold-silver ore from Specie Payment vein, Gilpin County, Colo. SPH, sphalerite.

As would be expected, composite ores are most abundant in the border regions between areas characterized by pyritic ores and areas of galena-sphalerite ores. The metal content of the composite ores is extremely diverse; it has all the variability that characterizes each component type and varies also with the proportions in which the two component types are mingled.

ALTERATIONS OF WALL ROCK NEAR SULPHIDE ORES.

The predominant wall-rock alterations associated with the three types of sulphide ores just described consist of the development of sericite and pyrite. Even near fissure fillings that consist predominantly of galena and sphalerite pyrite is the principal sulphide developed in the walls. Carbonates (usually calcite or siderite)



PHOTOGRAPH OF POLISHED SURFACE OF ORE OF COMPOSITE TYPE FROM FOURTH OF JULY MINE, NEAR CENTRAL CITY, COLO.

Pyritic ore has been brecciated and the fracture openings filled with ore of the galena-sphalerite type. Two-thirds natural size.

are developed near some veins and not near others; they are much more abundant near ores of the galena-sphalerite type than near the pyritic ores. In their early stages the alterations are markedly selective, the minerals showing differing susceptibilities to alteration and yielding different alteration products, thus indicating a chemical interchange between certain rock minerals and the mineralizing solutions. Chlorite and epidote, formed locally in the early stages of alteration, are during a later stage replaced by sericite. The earlier effects of alteration vary in different kinds of rocks, but the final products of the process are similar whatever the original character of the rock.

TELLURIDE ORES.

The telluride ores of the quadrangle show more diversity in mineral character than the sulphide ores of gold and silver, and knowledge concerning them is less definite. It is not certain that all of them were formed at the same time.

Tellurides of gold and silver have been found in close association with sulphide ores of gold and silver in the Gem and Casino mines, near Idaho Springs, and in the Kokomo, Sleepy Hollow, and Gregory mines, near Central City, but the writers were unable to procure specimens that showed the mutual relations of sulphides and tellurides. It is uncertain, therefore, whether the tellurides of such veins were deposited during the sulphide mineralization or represent a separate mineralization. In the mines that have been the largest producers of telluride ores the tellurides, although associated with some sulphides, were not components of typical sulphide ores of the types that have been described but occurred in entirely different mineral associations which will be briefly described. In the East Notaway and West Notaway mines, near Central City, the tellurides occur as a constituent of small veins, characteristically 1 inch to 3 inches wide, which consist mainly of dark-gray fine-grained quartz with minor amounts of fine-grained pyrite and antimoniacal tennantite. Locally there are networks of small veinlets instead of a single vein. Microscopic study shows that all the vein minerals belong to the same period of mineralization, but sulphides are commonly most abundant near the walls of the veins and the telluride is most abundant near the center. The telluride, which is sylvanite, usually forms isolated bladelike or tabular crystals in the quartz, but locally it is contemporaneously intergrown with tennantite. The telluride veins cut dikes of Tertiary monzonite porphyry and cut a typical sulphide vein of the pyritic type (the Homestake).

The most important present producers of telluride ores are the War Dance mine, near Central City, and the Treasure Vault, near Idaho Springs. In both these mines the tellurides are associated with abundant fluorite and with pyrite, resembling in these respects the ores of Cripple Creek. In the War Dance mine, which afforded the best opportunities for study, the telluride ore forms networks of small veinlets and irregular replacements of the wall rock near minute fractures. The ore minerals are fluorite, quartz, pyrite, and a telluride of gold and silver that is probably sylvanite. The telluride occurs as small flakes or plates of pale brass color, usually inclosed by fluorite. Free gold is present in some of the ores of this type, but as the specimens available were not adapted to microscopic study it could not be determined whether the gold was primary or a product of oxidation. In the War Dance mine a sulphide vein of the composite type occurs close to the telluride ore. This sulphide vein is not known to carry tellurides and is poor in gold. Hence it is probable that the two ore types were not contemporaneous.

Telluride ores of gold and silver occur near Eldora, in Boulder County, but as none of the mines could be entered the writers are unable to add anything to the published descriptions of Rickard[1] and Lindgren.[2]

URANIUM ORES.

Uraninite or pitchblende occurs in nature (*a*) in small amounts in granite pegmatites and (*b*) in intimate association with commoner metallic minerals in a few ore deposits. Quartz Hill, near Central City, is the one important locality in the United States and one of the few in the world that exemplifies the second mode of occurrence. For a number of years a small and sporadic production has come from this locality and has been used mainly in experimental work and for museum specimens. Pitchblende has been found in seven mines of Quartz Hill, all within an area of less than one-fourth of a square mile in extent. (See Pl. X.) All these mines have produced sulphide ores of gold and silver, and in most of them the pitchblende has been of very subordinate importance.

Microscopic study of the ores shows conclusively that the uraninite is intergrown contemporaneously with chalcopyrite and probably with quartz and pyrite, but that it is sharply cut by veinlets composed of galena, sphalerite, chalcopyrite, pyrite, and quartz. The minerals contemporaneous with the uraninite are those characteristic of the pyritic type of gold-silver ores, whereas the minerals of the transecting veinlets are those characteristic of the galena-sphalerite type of gold-silver ores. From the evidence available it therefore appears probable that the uraninite ores form merely a local and unusual variety of the pyritic type of gold-silver ores. They appear to represent a mineralogic variation of the same order as the occur-

[1] Rickard, T. A., The veins of Boulder and Kalgoorlie: Am. Inst. Min. Eng. Trans., vol. 33, p. 68, 1902.

[2] Lindgren, Waldemar, Some gold and tungsten deposits of Boulder County, Colo.: Econ. Geology, vol. 2, pp. 453–463, 1907.

rence of enargite in some of the pyritic veins near Russell Gulch. The Quartz Hill deposits contrast strongly with the pitchblende deposits of Cornwall and the Erzgebirge in their entire lack of nickel and cobalt minerals.

TUNGSTEN ORES.

The tungsten ores of Boulder County have been described at length by George and Crawford[1] and were not investigated in detail by the present writers. The principal mineral is ferberite, but with it are associated in small amounts several of the minerals scheelite, pyrite, chalcopyrite, galena, sphalerite, molybdenite, gold tellurides, and possibly fluorite and adularia. While no conclusive proofs have been obtained, these mineral associations have led most of the geologists who have studied the deposits to believe that they are closely related to the gold-silver deposits of the region and are probably of nearly the same age. Three features noted by the present writers appear to have a bearing on their origin and their relation to the other ore classes of the region: First, in the region where the tungsten ores are most abundant they almost wholly supplant other types of ores. Second, they occur in the only part of the quadrangle in which Tertiary dikes of andesitic or basaltic composition are abundant and adjacent to the only monzonite stock which exhibits extreme differentiation into dark-colored rocks, including iron ores. Third, the tungsten district lies between an area of productive gold-silver veins on the west and a region barren of valuable mineral deposits on the east. These relations and the mineral associations already cited are in harmony with the view provisionally adopted by the present writers that the tungsten ores represent an unusual phase of the general Tertiary mineralization of the region and that their origin is possibly connected in some way with the unusual development of dark-colored iron-rich rocks within the monzonite magmas of the area between Nederland and Caribou.

COPPER ORES.

In a region characterized by fissure veins that are valuable mainly for the gold and silver they contain the copper ores of the Evergreen mine, near Apex, stand unique as regards both mineral character and mode of occurrence. Their unusual features attracted the attention of Étienne Ritter,[2] who showed that the copper sulphides crystallized contemporaneously with the other minerals of the rock.

The primary ore minerals of the Evergreen mine are bornite and chalcopyrite. These minerals do not occur in fissure veins, but as con-

[1] George, R. D., and Crawford, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Survey First Rept., 1908.

[2] Ritter, É. A., The Evergreen copper deposit, Colorado: Am. Inst. Min. Eng. Trans., vol. 38, pp. 751–765, 1908.

stituents of dikes of monzonitic composition that are clearly offshoots from neighboring monzonite stocks. In places the monzonite has so shattered the schist and pegmatite wall rock that an igneous breccia has resulted. Chalcopyrite and bornite occur in the igneous matrix of this breccia, but not in the wall-rock fragments. In addition to its sulphide content, the monzonite of the Evergreen mine exhibits other unusual features; it carries small prisms of wollastonite locally in great abundance, and in a few places, in close association with the sulphides, it contains garnet.

The bornite does not appear to be an alteration product of the chalcopyrite, for the occurrence of bornite inclosed by chalcopyrite is as common as the reverse relation, and the bornite does not rim the chalcopyrite or follow incipient fractures in it. On the contrary, the two minerals are very irregularly associated, locally in a fashion resembling a graphic intergrowth. The chalcopyrite and bornite do not appear to be replacements of the silicates of the monzonite, although they may have corroded the silicates slightly in places; on the contrary, they appear to have crystallized at essentially the same time as the rock silicates.

Rogers,[1] in a recent paper, figures chalcocite associated with bornite from the Evergreen mine and suggests that the chalcocite is a product of upward enrichment. Chalcocite is a very inconspicuous mineral at this mine and is seldom recognizable except under the microscope. In one of the specimens examined chalcocite is irregularly associated with chalcopyrite and bornite. The origin of this particular chalcocite is uncertain. In most other specimens, however, chalcocite has developed along incipient fractures in the bornite and along contacts between bornite and silicate minerals. This relation between chalcocite and bornite is totally different from the relation between bornite and chalcopyrite and is taken to indicate that the chalcocite is secondary. As the mine workings are all shallow it is impossible to say whether the chalcocite was deposited by ascending or by descending solutions, but the writers are much inclined to accept the latter and more usual explanation of its origin.

The writers believe that the dominant sulphides of this mine, chalcopyrite and bornite, were probably concentrated by differentiation from the monzonite magma, and that the wollastonite and garnet of the ore-bearing dikes indicate an absorption of calcareous material from wall rocks.

The ore obtained at this mine is said to average about 3 per cent of copper and $4 to $5 to the ton in gold and silver. Its distribution, however, is irregular, and with the exception of the large chamber stope on the tunnel level no large bodies have been encountered.

[1] Rogers, A. F., Secondary sulphide enrichment of copper ores with special reference to microscopic study: Min. and Sci. Press, Oct. 31, 1914, p. 686.

Only a few carloads have been shipped, and the work is still largely exploratory. The ore is unquestionably to be sought in and near the dikes, but as the sulphides are so unevenly distributed in the dike rock no prediction of the probable value or extent of the ore can be made.

TITANIFEROUS IRON ORES.

The Tertiary monzonite stocks of Caribou and of Bald Mountain, northwest of Caribou, unlike the other monzonite stocks of the region, inclose a number of bodies of dark-colored rock that are clearly products of differentiation within the monzonite magmas. The extreme products of this process are several bodies of iron ore that show some interesting features bearing on the origin of titaniferous iron ores and the mechanism of magmatic differentiation.

The greater part of the Caribou and Bald Mountain stocks consists of monzonite and quartz monzonite of gray color and medium coarseness. Inclosed within these rocks and forming not more than 5 per cent of the surface of the stocks are a number of small irregular bodies of dark-colored rocks rich in iron-bearing minerals. The largest of these bodies is only about a quarter of a mile in greatest diameter. Within these areas of dark-colored rock in turn occur small bodies of titaniferous iron ore. In places the contacts between the iron ore and the dark rock that incloses it and between the dark rock and the monzonite are sharp, but in many other places complete gradations occur between these rock types, so that in general it is clear that the iron-rich rocks were differentiated from the monzonite magma, the differentiation being followed locally by intrusion of the darker into the lighter types. The rocks present are quartz monzonite, monzonite, olivine monzonite, gabbro, hornblende gabbro, hornblendite, magnetite-rich gabbro, magnetite peridotite, and magnetite pyroxenite.

The ores have been studied by Jennings,[1] who says: "These interesting deposits have little or no economic importance, but are excellent examples of iron ores of igneous origin." Singewald,[2] who has also studied the deposits, concludes that, "The best of the ore is only medium grade and the ore lenses are very small. On account of its small size the deposit can never have any economic value."

As is well known, no iron ores containing appreciable amounts of titanium are now used in the iron industry, though experiments looking toward their utilization are now in progress. The presence of titanium is not injurious in steels used for certain purposes; in

[1] Jennings, E. P., A titaniferous iron ore deposit in Boulder County, Colo.: Am. Inst. Min. Eng. Trans., vol. 44, pp. 14–25, 1913.

[2] Singewald, J. T., The titaniferous iron ores in the United States: U. S. Bur. Mines Bull. 64, pp. 126–128, 1913.

fact, titanium is the material most widely used to give steel certain desired properties. Its detrimental effect in an iron ore is due to the fact that it produces a refractory slag that is difficult to handle in the blast furnace, and 0.5 per cent seems to be almost as detrimental in this respect as 10 or 15 per cent. The percentages of magnetite and titanic oxide in samples of the Caribou ore analyzed by Jennings and by the Geological Survey are as follows:

	1	2	3
Magnetite (Fe_3O_4)	64.73	30.55	23.90
Titanic oxide (TiO_2)	4.48	2.69	2.52

1, E. P. Jennings, analyst; 2, 3, lean ore, George Steiger, analyst.

Even if the metallurgic difficulties involved in the high titanium content can be overcome, the inaccessibility of these deposits and their small size preclude all possibility of successful exploitation.

DOWNWARD ENRICHMENT.

GENERAL CONDITIONS.

It is well known that when the surface portions of ore deposits are attacked by the gases of the atmosphere and by water of surface origin and the dissolved substances it contains a part of the ore is carried away, either mechanically or in solution, while another part remains behind. The metals carried away may become widely scattered and lost, so far as concerns the miner of to-day, or they may be concentrated elsewhere in ore deposits of different types, such as the gold-bearing gravels of the district here described or the copper ores found in surface sandstones in other districts. The metals that remain behind work their way downward into the ore body, either mechanically or in solution; those carried mechanically do not penetrate far and those descending in solution are liable to reprecipitation through agencies that will be noted later.

Such processes as those outlined above must, at their beginning, as when erosion first exposes an ore body, result in a depletion in the value of the surface ore, but as erosion progresses the metals left behind come in time to represent a residuum from tens, then hundreds, and perhaps thousands of feet of ore that has been eroded away. To use a commercial simile, the value of the ore in the upper part of a deposit may thus increase "at compound interest." Such a process is termed "downward enrichment," the adjective being used to distinguish it from enrichment caused by ascending thermal solutions.

The gold-silver ores are the only ones in this region that have been affected in any considerable degree by downward enrichment, but as these constitute the dominant ore class, the process has been one of much importance. Enrichment in one or all of the metals gold, silver, and copper has taken place; enrichment in lead and zinc has been insignificant. As in most mountainous regions, the ground-water level is very irregular; in most veins it originally stood 50 to 150 feet below the surface.

GOLD ENRICHMENT.

Weathering of the ore in the oxidized zone results in a partial freeing of the gold from its matrix, thus exposing it to mechanical concentration and to the solvent action of waters that enter the upper parts of the lodes. The enrichment in gold observed in the oxidized zone of ore bodies is probably in large part the result of mechanical concentration during weathering, a process well understood and requiring no discussion here, but solution and redeposition of gold may also have taken place. It would be expected that whatever gold was taken into solution would soon be reprecipitated, for it is well known that ferrous sulphate and most of the common sulphides, including pyrite, chalcopyrite, and galena,[1] are very effective precipitants of gold from a chloride solution. As several of these precipitating agents are abundant in the lower part of the oxidized zone it appears unlikely that much gold in solution[2] could successfully pass them; if it did it could hardly travel far below the water level before being precipitated by the primary sulphides. These deductions appear to be borne out by the facts of field observation, which afford abundant evidence of enrichment in gold in the oxidized zone but no certain evidence of gold enrichment below it.

Enrichment in gold in the oxidized zone is characteristic of all the types of gold-silver ores in the region—the pyritic ores, the galena-sphalerite ores, the composite ores, and the telluride ores. Its effects are most striking, however, in certain ores of the galena-sphalerite type which, where unoxidized, carry only negligible amounts of gold, usually less than 0.1 ounce to the ton, whereas where oxidized they may carry 1.5 to 3 ounces of gold to the ton. These are the so-called silver veins whose surface portions were worked by the pioneers for gold alone.

Although data showing in a systematic way the distribution of gold below the oxidized zone are rather meager, such information as is available fails to indicate much gold enrichment below the water level. In the Iron mine, in Russell Gulch, for example, which develops a typical pyritic vein, complete records of a careful sampling

[1] Palmer, Chase, and Bastin, E. S., Metallic minerals of precipitants of silver and gold: Econ. Geology, vol. 8, pp. 156–160, 1913.

[2] No account is here taken of colloidal gold solutions, of whose importance in nature little is known.

of all parts of the vein fail to show any systematic change in the gold content below the oxidized zone.

SILVER ENRICHMENT.

Silver enrichment contrasts strongly with gold enrichment in this district in that there is impoverishment rather than enrichment of silver in the oxidized zone and notable enrichment below the oxidized zone. Furthermore, silver enrichment is practically confined to the one type of galena-sphalerite ores. The primary silver minerals of the region are silver alloyed with gold and silver-gold tellurides. Argentite has not been authoritatively reported. The secondary silver minerals are native silver, cerargyrite, pearceite, polybasite, and proustite.

It is well known that silver is more readily taken into solution in the oxidized zone than gold and that fewer metallic minerals can reprecipitate it.[1] The poverty in silver of the oxidized zone is thus readily understood.

In most mine waters of surface origin the principal negative radicles present are Cl, CO_3, HCO, and SO_4. As compounds of silver with all these radicles are known, it is customary to consider the dissolved silver as existing in distributed balance with as many of these radicles as may be present. Most of the silver balanced by chlorine is likely to be reprecipitated in the oxidized zone as the difficultly soluble silver chloride (cerargyrite or horn silver). Cerargyrite is not a common silver mineral in this district, and its rarity is attributed to the low chlorine content of the surface waters. The silver balanced by carbonate and sulphate radicles may pass downward below the oxidized zone. In sulphide ore bodies like those under consideration most of the silver is presumably in balance with SO_4.

The silver is redeposited below the ground-water level principally as pearceite and proustite and very subordinately as polybasite and native silver in vugs or fractures in the primary ore or as replacements of the primary ore minerals, both metallic and nonmetallic. It is significant that in the ores of this region arsenic greatly predominates over antimony, both in the primary ore, where it occurs principally in tennantite, and in the enriched ores, where it occurs in pearceite and proustite. The chemistry of the formation of the arsenosulphides of silver is too little understood to justify discussion in a summary of this kind, but geologic observations in this region suggest some limiting conditions that may be a guide to experimental chemical work.

The first point is that the ores carrying secondary arsenosulphides of silver almost invariably carry abundant primary siderite or calcite; the solutions that deposited them were therefore not highly acid.

[1] Palmer, Chase, and Bastin, E. S., op. cit., pp. 169–170.

A second significant observation is that downward enrichment in silver is practically confined to ores of the galena-sphalerite type in spite of the fact that primary silver is abundant in all the other types of gold-silver ores. The dominant minerals of the veins showing silver enrichment are galena, sphalerite, and carbonates (calcite, siderite, or rhodochrosite, one or all); pyrite and chalcopyrite are present in smaller amounts. In the pyritic type of ores, in which silver enrichment is conspicuously absent, pyrite and quartz are the dominant minerals, and tennantite and chalcopyrite are less abundant.

The causes for this restriction of silver enrichment to veins of a certain mineral composition are undoubtedly complex, but the presence of carbonate gangue minerals in the ores that show silver enrichment is believed to be a most important factor. Their presence has led to an early neutralization of the free sulphuric acid in the descending silver-bearing solutions. Much of the carbonate in these veins is ferruginous (ferruginous calcite and siderite), and this by reaction with sulphuric acid yields ferrous sulphate, an effective silver precipitant. In a timely and suggestive paper Nishihara[1] has compared the neutralizing effect of various carbonates, silicates, and sulphides on sulphuric acid and their activity in reducing ferric sulphate to ferrous sulphate. It is very significant that pyrite, quartz, and chalcopyrite, the principal minerals of the pyritic type of ores, were in Nishihara's experiments comparatively ineffective in neutralizing sulphuric acid and in reducing ferric to ferrous sulphate. Galena and sphalerite and, of course, the carbonates are comparatively efficient in neutralizing sulphuric acid and galena is fairly active in reducing ferric sulphate. Furthermore, galena and sphalerite in solutions of sulphuric acid or ferric sulphate generate hydrogen sulphide, which may precipitate secondary sulphides. Nishihara has also shown that apparently pure galena from several localities, among them Idaho Springs, carries small percentages of manganese, which presumably occurs as the manganese sulphide alabandite mixed with the galena. This sulphide evolves hydrogen sulphide very actively when in contact with acid sulphate solutions, and if present in the enriched veins of this region may have exerted a considerable precipitative influence.

It appears, therefore, that the mineral composition of the galena-sphalerite veins that show enrichment is such as to favor early neutralization of acidity of the silver-bearing sulphate solutions descending from the oxidized zone, the formation of ferrous sulphate at the expense of ferric sulphate and sulphuric acid, and the development of hydrogen sulphide. All these features are believed to favor silver precipitation. In the ores of the pyritic type, on the other

[1] Nishihara, G. S., The rate of reduction of acidity of descending waters by certain ore and gangue minerals and its bearing upon secondary sulphide enrichment: Econ. Geology, vol. 9, pp. 743–757, 1914.

hand, the conditions favor the persistence of acidity and the retention of the iron in the ferric state; silver taken into solution in the oxidized zone is therefore likely to remain in solution and eventually to enter the general ground-water circulation and be lost so far as the local ore deposit is concerned.

In some of the deposits of the galena-sphalerite type, as for example those of the Topeka and Seaton veins, the primary ores are of workable grade, but in many others, as for example those near Lawson and on Silver Hill, north of Blackhawk, only the ores that have been enriched in silver can be profitably mined. These secondary ores form the typical silver ores of the miners of this region, their gold content being characteristically small. The workability of any of the primary ores is usually due to the fact that the primary gold content, rather than the primary silver content, is above the average.

Veins in which silver enrichment of the type here discussed has taken place to a considerable extent occur principally in four localities—(1) near Lawson and Empire station, (2) on or near Seaton Mountain, north of Idaho Springs, (3) on Silver Hill, near Blackhawk, and (4) near Caribou, with occasional occurrences elsewhere.

The silver content of the enriched ores shows much more variability than that of the primary ores. This is obviously due to the occurrence of the secondary silver minerals in fractures and as localized replacements rather than in even distribution through the ore. The silver content of ores of smelting grade varied from a few tens of ounces up to a thousand ounces to the ton, or even more in picked lots; 6½ tons shipped in 1870 from the Idaho mine, near Caribou, averaged 977½ ounces of silver to the ton, and two lots of ore from the Almaden mine, on Fall River, gave on assay, according to the manager of the property, the following extraordinary results in ounces to the ton:

	Gold.	Silver.
149 pounds	0.38	5,810.30
510 pounds	.487	4,084.92

The decrease in silver content of the enriched ores with increasing depth has been the prime factor in the decline of the silver mines of this district, but a factor of subsidiary importance was the great decrease in the market value of silver, from $1.32 an ounce in 1872 to 63 cents in 1894, a fall of about 50 per cent.

COPPER ENRICHMENT.

Downward enrichment in copper is not conspicuous in any of the mines and is of little economic importance. Commonly it is restricted to the development of thin films of chalcocite or bornite on chalcopyrite in the upper portions of pyritic ore bodies, but in some veins of the galena-sphalerite type, as already mentioned, small amounts of secondary chalcopyrite are developed.

GENESIS OF THE PRIMARY ORES.

RELATION OF MINERALIZATION TO VOLCANISM.

The ore deposits of Gilpin County form part of a broad mineralized belt whose diverse types of ore deposits have one unifying feature, their invariable association with Tertiary igneous rocks. Beyond the regions characterized by these rocks the ore deposits disappear. This association, suggestive though it may be, would certainly not be sufficient basis for concluding that the ores and the Tertiary igneous rocks are genetically related, were it not for the fact that a similar association of ores and igneous rocks characterizes practically every region where lode deposits of gold and silver have been studied geologically. Furthermore, it seems probable from the geologic observations within this region that the mineral veins were formed late in the period of "porphyry" intrusion, for the veins are younger than most of the "porphyry" but older than a few scattered "porphyry" dikes. Finally, two classes of ores, the titaniferous iron ores and the Evergreen copper ores, are products of differentiation from the monzonite magmas. It is believed, therefore, that a genetic connection exists between the mineral veins of this region and the Tertiary igneous rocks.

AGENT OF ORE DEPOSITION.

With the exception of the iron and copper ores just mentioned, all the ore deposits of the region are believed to have been deposited by thermal solutions which escaped from the "porphyry" magmas, probably during their crystallization. The "porphyries" now exposed at the surface may have given off solutions that deposited ores at horizons above the present surface, but the solutions which deposited the veins and stockworks came from bodies of igneous rock that are still deeply buried, as is shown by the fact that the veins, with few exceptions, cut the "porphyries" now exposed. There appears to be no basis for the belief locally current that the occurrence of an ore deposit in or near "porphyry" is a favorable indication; the relations between ores and "porphyries" are of a much larger and more generalized order than that implied in any such concept.

REGIONAL VARIATIONS IN MINERALIZING SOLUTIONS.

Not only did the composition of the mineralizing solutions change during the ore-forming period, as is shown below, but there is evidence that solutions which were strictly contemporaneous were of different composition in different parts of the district. The ores of the pyritic type, for example, appear to have been deposited about contemporaneously in the early part of the mineralization period, yet among these are several subtypes, narrowly restricted in distribution, which show mineralogic peculiarities. Such are the enargite and fluorite bearing veins and the pitchblende veins whose limits of distribution are shown in Plate X. Similar variations occur in ores of the galena-sphalerite type—for example, the occurrence of rhodochrosite in a few veins on Seaton Mountain and near the head of Gilson Gulch. Such variations can not be satisfactorily explained by differences in the nature of the wall rocks or in other external conditions and must be attributed to local peculiarities in the composition of the solutions that rose through the fissures and deposited the ores.

SEQUENTIAL VARIATIONS IN MINERALIZING SOLUTIONS.

It has been shown by a large number of observations in this region that where the sulphide ores of the two principal types, the pyritic type and the galena-sphalerite type, occur together, the pyritic ores are invariably the older. The periods during which the ores of the two types were deposited were separated by an interval long enough for the fracturing of the pyritic ores by renewed movement along some of the veins and for the development of some entirely new fractures. This interval may not everywhere have been of the same duration, but probably, in geologic terms, it was short and is to be interpreted as an episode in a single general ore-forming period rather than as a notable interval between two distinct periods. Certainly the ores of both types were deposited under similar general conditions as regards depth and temperature, followed the same or parallel lines of fracturing, and have, broadly, the same distribution. At Leadville, within the same great mineral province, where ores similar to the pyritic and galena-sphalerite types of this quadrangle are also present, the pyritic portions of the ores were, in general, the first to be deposited, but, according to J. D. Irving,[1] there is no evidence of an interval between their deposition and the deposition of the portions of the ores rich in galena and sphalerite. Evidence of an interval, if present, would presumably be less readily recognizable in replacement ores like those of Leadville than in ores that are fissure fillings, or it may be that the mineralization which progressed pulsatingly in Gilpin County progressed more uniformly at Leadville.

TEMPERATURE AND PRESSURE OF ORE FORMATION.

For his concept of the temperature and pressure under which ore deposits were formed the geologist is dependent upon (1) physio-

[1] Oral communication.

graphic and stratigraphic evidences of the extent of erosion subsequent to mineralization, (2) direct laboratory data in regard to the range of stability of ore minerals, and (3) indirect knowledge of the conditions under which certain ore minerals are stable, based on estimates of the amount of postmineral erosion in a large number of mining districts. Through the application of one or more of these criteria it is generally possible to determine whether the ores were formed under conditions of great, moderate, or slight intensity as regards temperature or pressure, or both, even though it may not be possible to express these conditions accurately in degrees of temperature or in pounds per square inch of pressure.

The application of the first of these criteria to the Gilpin County deposits is attended by many uncertainties, but from the data available 7,000 to 11,000 feet appears the most probable depth of formation of most of the deposits. At a depth of 9,840 feet (3,000 meters) the hydrostatic pressure would be about 300 atmospheres and the rock pressure about 810 atmospheres. Under the normal increase of temperature with increasing depth the temperature at a depth of 9,000 feet would be about 100° C. This may be regarded as the minimum possible temperature of ore formation, but it gives no clue to the actual temperature.

The mineralogy of the ores is presented in the accompanying table, which shows that in all the ores believed to be deposits from thermal waters there is an entire absence of minerals characteristic of very high temperature, high pressure, or both, or of low temperature and shallow depth. The absence of silicates, except adularia and sericite, is noteworthy. Oxides, except silica, are not present as primary minerals. Pyrrhotite, a sulphide characteristic of intense conditions, is absent. Chalcedony, a mineral occurring usually in deposits of shallow origin, though locally in those formed under conditions of moderate intensity, is present only in small amounts in a few telluride veins. Realgar, orpiment, stibnite, and many other minerals characteristic of deposits formed at slight depth are absent. On the other hand, tennantite and enargite, which are commonly found in deposits formed under moderately intense conditions, are abundant in certain of the veins of this region.

The mineralogic as well as the physiographic and stratigraphic evidence therefore points to the formation of the gold-silver lodes, the pitchblende ores, and probably also the tungsten ores under conditions of moderate intensity. The depth of formation was probably 7,000 to 11,000 feet. Direct evidence of the temperature of formation is lacking, but from analogy with similar deposits elsewhere its probable limits may be placed at 150° to 300° C.

The following table includes minerals developed metasomatically in wall rocks, as well as those that are fissure fillings:

Ore minerals of Central City quadrangle, Colo.

[P, Primary minerals; S, minerals of secondary sulphide zone; O, oxidation products; * mineral rare.]

Minerals.	Primary ores crystallized from magmas.						Primary gold-silver ores deposited by ascending thermal solutions under moderately intense conditions.								
	Caribou iron ores.			Evergreen mine copper ores.			Pyritic ore type.			Galena-sphalerite ore type.			Telluride ores.		
Native elements:															
Gold				P			P	S?	O	P	S?	O	P	S?	O
Silver				P			P	S?	O?	P	S	P	P	S?	O?
Copper									O						
Bismuth							P*			P*					
Sulphur									O			O			O?
Sulphides:															
Pyrite				P?			P			P			P		
Chalcopyrite				P			P	S*		P	S				
Bornite				P				S		P*	S*				
Covellite								S							
Chalcocite								S			S*				
Galena				P?			P*			P	S*				
Sphalerite				P?			P*			P					
Molybdenite							P*			P*			P*		
Bismuthinite							P*								
Tellurides:															
Sylvanite							P?			P?			P		
Petzite													P*		
Sulpho-compounds:															
Tetrahedrite							P*			P?					
Tennantite							P			P					
Enargite							P			P*					
Pearceite											S				
Proustite											S				
Polybasite											S				
Stephanite											S?				
Haloids:															
Cerargyrite												O*			
Fluorite							P			P?					
Oxides:															
Quartz				P			P			P			P		
Chalcedony													P		
Tenorite									O*						
Hematite			O			O			O			O			O
Zincite												O*			
Ilmenite	P														
Ilsemannite ($MoO_2.4MoO_3$)															O*
Magnetite	P			P											
Limonite			O			O			O			O			O
Carbonates:															
Calcite				P?	S*		P			P					
Siderite							P			P					
Rhodochrosite										P					
Smithsonite												O*			
Cerusite												O*			
Malachite						O			O			O*			
Azurite						O			O			O*			
Aurichalcite												O*			
Silicates:															
Orthoclase				P											
Adularia										P*			P*		
Soda-potash feldspar							P*								
Albite				P											
Plagioclase (calcic)	P			P											
Augite	P			P											
Wollastonite				P											
Garnet				P											
Olivine	P														
Zircon				P											
Sericite							P			P			P?		
Biotite	P														
Epidote										P*					
Roscoelite													P		
Chlinochlore										P*					
Serpentine			O												
Calamine												O*			
Titanite				P											
Phosphates:															
Apatite	P														
Uranates:															
Uraninite							P*								
Sulphates:															
Barite										P			P*		
Hydrous sulphate of iron and copper						O			O						
Basic sulphate of uranium, exact composition not determined, found coating uraninite at Wood mine, canary-yellow									O						
Goslarite													O*		

COMPOSITION OF MINERALIZING SOLUTIONS.

The composition of the solutions which deposited the gold-silver ores and pitchblende ores may be inferred in a qualitative way from the mineralogy of the ores and the wall-rock alterations. To summarize without detailing the evidence, it appears that these solutions were alkaline or neutral in character and that they were rich in alkali earths; during the early stages of the mineralization they were rich in iron and silica and during the later stages rich in lead, zinc, carbonate, and bicarbonate; they carried smaller amounts of copper, arsenic, antimony, gold, and silver, and locally they carried manganese, sulphate, barium, tellurium, fluorine, uranium, and vanadium.