GEOLOGY

OF

WESTERN ORE DEPOSITS

BY

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"PROSPECTING FOR GOLD AND SILVER IN NORTH AMERICA"
"GEOLOGY OF COLORADO COALFIELDS"
ETC., ETC.

NEW EDITION ENTIRELY RE-WRITTEN AND ENLARGED
WITH 300 ILLUSTRATIONS

1905
THE KENDRICK BOOK AND STATIONERY COMPANY,
PUBLISHERS, DENVER, COLORADO

THE SMITH-BROOKS PRESS
DENVER, COLO.

PREFACE TO THE SECOND EDITION.

This second edition is the result partly of the success of the first, but mainly of a desire felt by the author to bring his subject up to date. It is now over ten years since the earlier edition was written, and the science of geology, the development of mines and the rapid discoveries of new regions have advanced at such a pace that what then appeared as new is now commonplace. An example is the discovery and development of Cripple Creek, a district then in its infancy, receiving but scant attention in the original work. The same has been the case with many other mining camps, in Colorado and elsewhere.

It has been the writer's object to illustrate the principles of mining geology rather than to dilate on any particular rich or noted mine. If a small mine illustrates some important geological or other interesting feature in the science of mining, attention is given to that mine rather than to its more noted neighbor. Preference is given to Colorado's mines because the writer is more familiar with them, and they well illustrate the leading principles. Those outside of Colorado are selected and described as enlarging on principles previously discussed.

The first part of the book relates to general features of mining geology. This is followed by illustrations of these, drawn from Colorado mining camps, and by a further illustration and confirmation of them from some of the noted mining camps of the Western States. To illustrate the state or territory mentioned, some characteristic mine or mining region has been selected.

The author acknowledges his indebtedness to the United States Geological Survey; to the works of Messrs. Kemp, Van Hise, Stretch and other writers on ore deposits; and, in the revision and preparation of this edition for the press, to Mr. Gerald R. McDowell, of Denver, and Dr. Regis Chauvenet, late president of the Colorado School of Mines; also, to *Mines and Minerals*, of Scranton, Pennsylvania, for the loan of plates and for other courtesies.

CHAPTER I.

GENERAL GEOLOGY.

Without going into the speculative origin of this earth from a nebular mist and a condensing magma, we will take the rocks associated with ore deposits as we actually find them in Colorado and the Western States.

ARCHEAN GRANITIC SERIES.

The first and most ancient rock series, which underlies all others, and may be called the bedrock of the world, is the granitic. This is commonly assumed to be of Archean age, or to have been formed and upheaved in the earliest period of the world's existence of which we have any cognizance. This is doubtless true in the majority of cases, but there is evidence that some granites, such as those of Pike's Peak and the Cripple Creek region, were upheaved or erupted at a later date.

The origin of the granitic series has long been a matter of interesting speculation. By some it was supposed to represent a metamorphic condition of aqueous sediments, originally stratified; and the term metamorphic granite was applied to some granites in distinction from others of apparently true eruptive origin. Massive amorphous granite was assumed to represent a stage of ultrametamorphism which had obliterated all bedding and other signs of sedimentary origin, while the bedded gneisses and laminated schists were supposed to represent or retain some evidence of former sedimentary structure. The consensus of modern geology favors the view that the whole series, with the exception perhaps of the Algonkian quartzites and schists, is of true igneous or Aqueo-igneous origin, and that the rude bedded appearance and laminated structure is due to mechanical shearage stresses and other dynamical movements after the granitic rocks were consolidated.

Assuming the general igneous origin and character of the granitic series, the rocks differ but little from the undoubted igneous rocks known as porphyries. We do not, however, commonly find granite intruding into and spread out between the planes of stratification of the later true sedimentary rocks, as is the case with the porphyries, diorites, etc., or poured out on the surface of the country, as seen in the more modern lava flows of rhyolite, andesite and basalt. Granite seems to keep its place geologically below all other rocks. When we find its peaks towering above the low lying sedimentaries, it is because it has been upheaved through them, or the latter have been removed by great erosion.

Within the interior structure or mass of the granite itself may be found later eruptive granites, as the fine grained aplitic granite and the granite dikes in the Cripple Creek region cutting through the older Pike's Peak coarse granite. Again, there are irregular masses of a granitic type within the granitic complex, commonly called pegmatites—granite in a much coarser crystalline condition, and containing less mica than the normal granite. These masses sometimes occur in very irregular forms, at times as dikes, at others like veins. It is often a question whether to consider these as true eruptive dikes or as zones formed by an excess of steam and mineralizing agencies.

Many of these pegmatitic forms, consisting of quartz and feldspar, constitute the gangue of the so-called "true-fissure," ore-bearing, quartz veins or reefs of many of our mining districts in a granitic region, for example, in Gilpin, Clear Creek and Boulder Counties, Colorado. Such ore-bearing veins may occur as independent veins wholly in the granite, or they may be at contact between granite and a true eruptive rock like porphyry, or the granite itself at the line of contact may be so decomposed and impregnated with ore as to practically constitute the ore zone, as in the Independence mine at Cripple Creek.

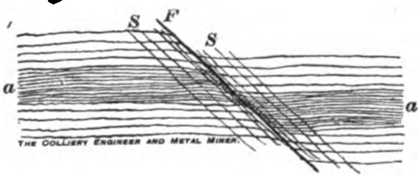


FIG. 1.—SHEAR ZONE AND FAULT, CRIPPLE CREEK.

A not uncommon repository for ore in granite is in *shearage zones*, that is, where the granite by dynamic shearage stresses or strains has been split into a zone of parallel cracks, more or less close, as at the Gold Coin Mine, of Victor, Colorado. Mineral bearing solutions enter these weak places, decompose the zone, silicify it, and deposit ore matter. The alteration and silicifying may progress so far as to obliterate all the partitions of the country rock, and reduce the whole, or a greater part of the sheared zone, to one wide so-called quartz vein. It is probable that many of our wide quartz veins in granitic rocks so originated.

In the bedded gneisses and laminated schists of the granitic series, veins may follow entirely the bedding or laminated planes. After following such planes for a while, they may cut across them, either at a right angle or obliquely. (Fig. 3.) In the case of the schists, if

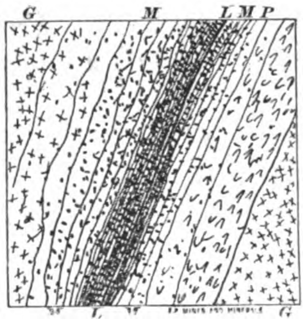


FIG. 2.—ORE IN SHEARAGE ZONE.

the veins follow the lamination planes, owing to the corrugations common to the schists, they are likely to occur

FIG. 3.—FISSURE VEIN, PARTLY CONFORMING TO STRATIFICATION PLANE, PARTLY DEVIATING FROM IT.

in a series of quartz lenses, and may prove more pockety and less continuous than if they had cut across the lamination.

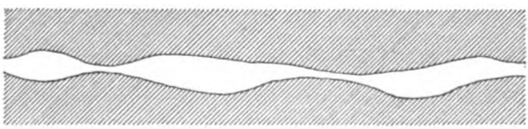


FIG. 4.—ILLUSTRATING LENTICULAR STRUCTURE.

Schists, again, are not infrequently impregnated with ores of decomposed former mineralized zones or fahl

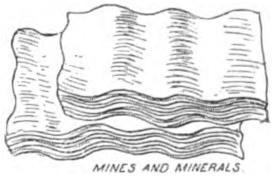


FIG. 5.—ILLUSTRATING FORMATION OF QUARTZ LENSES IN SCHISTS.

bands. This often occurs with copper solutions. Such zones may or may not be profitable to work.

FIG. 6.—QUARTZ LENSES IN CONTORTED SCHISTS.

THE ALGONKIAN SERIES.

A series of metamorphosed quartzites, conglomerates, conglomeratic gneisses, schists and slates are found in Colorado and various parts of the West flanking the Archæan granite complex conformably, or unconformably, and sometimes, as at Cripple Creek, within the granite complex itself, where they have been caught up by later erupted granite. The normal geological position of this series is between the granite complex and the overlying Cambrian sedimentary quartzites, hence they are sometimes called Pre-Cambrian rocks.

In Colorado patches of these are found in Coal Creek, South Boulder Cañon, in the Gunnison region, near Salida, and between Ironton and Ouray, in the San Juan region, along the Mears road. Along the Pacific coast and in British Columbia they occupy a wide and long area. As ore-bearing rocks the same remarks apply to them as to the older granitic series. They are liable to be

FIG. 7.—IDEAL SECTION OF THE FOOTHILLS OF THE ROCKY MOUNTAINS.

penetrated by igneous dikes and pegmatitic veins, and under similar conditions are as likely to carry ore as the older series. These rocks, although of a somewhat granitic character, appear to be genuine metamorphosed sediments, younger than the Archæan granite complex, but older than the Cambrian.

CAMBRIAN.

Lying unconformably upon the eroded edges of both the Algonkian and granitic complex are the Cambrian rocks. Along the foothills these sedimentary formations consist of conglomerates and sandstones, and in the heart of the ranges they are conglomeratic quartzites and vitreous white quartzites banded with iron oxides. In Colorado the Cambrian series rarely extends beyond two hundred feet in thickness, but in Montana and other regions it greatly exceeds this. The Cambrian rocks are not generally productive of ores, nor are thay favorable for mining, because of their excessive hardness. On Battle Mountain, near Red Cliff, Colorado, rich gold ore deposits, doubtless due to the proximity of eruptive rocks, occur in cavernous pockets. In Buckskin Cañon, South Park,

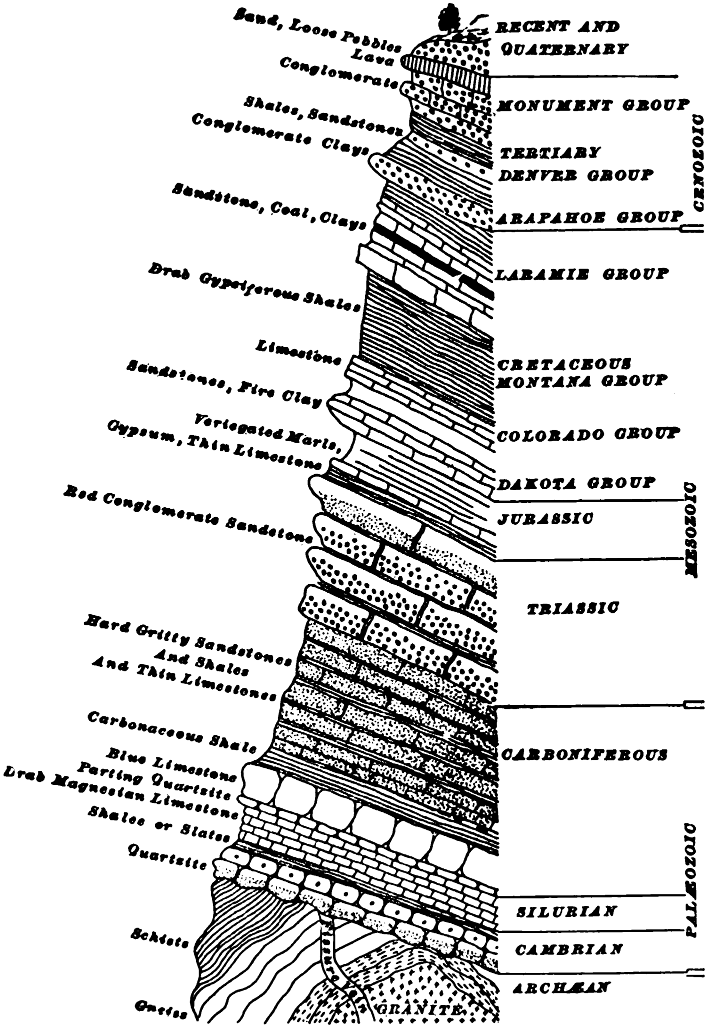


FIG. 8.—GENERALIZED VERTICAL GEOLOGICAL SECTION OF THE FORMATIONS OF THE ROCKY MOUNTAINS IN COLORADO.

the quartzites are locally impregnated with auriferous pyrite in proximity to an igneous sheet. Some ore deposits similarly situated were in former times profitably worked near Leadville.

The celebrated Homestake Mine, of the Black Hills, South Dakota, derives part of its gold ore from an impregnation of the Cambrian conglomerates, which were laid down as shores or beaches by the waves of the Cambrian Sea beating against the Archæan granite.

SILURIAN.

The Cambrian is succeeded above by the Silurian, consisting of thin bedded drab or light colored cherty, dolomitic limestones, locally known as white limestone or "short lime." This formation, usually not over two hundred and fifty feet thick, may carry some ore bodies in connection with intrusive sheets of porphyry, but is not so great a recipient of ore as the Carboniferous blue limestone above.

The Silurian series is separated from the Carboniferous in Colorado by a persistent bed of white quartzite about forty feet thick, known as the parting quartzite. It is in this zone that the Devonian properly belongs, but, with a few exceptions, the rocks of this period are not represented in the Rocky Mountains of Colorado. The exceptions are found in the Animas Cañon, in the southern part of the San Juan region, where Devonian fossils have been recognized in certain limestones and quartzites. At Eureka, Nevada, and in the Bisbee district, Arizona, there are Devonian limestones and sandstones in which are some important mines.

CARBONIFEROUS.

Resting upon the parting quartzites are the heavily bedded limestones of the Lower Carboniferous, from one hundred to two hundred feet thick. These rocks may be either a dolomite, as at Leadville, or in part a dolomite and in part a true limestone, as at Aspen. The prevailing color is a bluish gray, hence they are locally known as "Blue limestones." (See Fig. 9.)

This Lower Carboniferous is attested to by the occurrence of fossil shells, spirifers and corals. Round nodules of black chalcedonic cherts are found, while those in the Silurian dolomites are usually white.

These cavernous, soluble limestones have been the main recipients of ore, both at Leadville and Aspen, and in some other parts of the Rocky Mountains, when associated with intrusive sheets and dikes of porphyry. The solubility and jointed character of the rock make these limestones especially adapted for the reception of ore solutions and the deposit of ore by metasomatic replacement.

Above the Lower Carboniferous limestone is a very thick series, aggregating two thousand feet or more, in Colorado, of shales, quartzitic conglomerates or grits, and a few thin beds of limestone. This series is known as the Weber grit series, from the Weber Cañon, Utah, where the formation attains an extraordinary thickness, and represents in the West the Middle Carboniferous. In some of the black carbonaceous shales, fossil impressions of Carboniferous plants like those of the Eastern States occur, and some thin seams of true Carboniferous coal. The Weber grits are not remarkable for ore deposits in Colorado, except where they have been intensely intruded

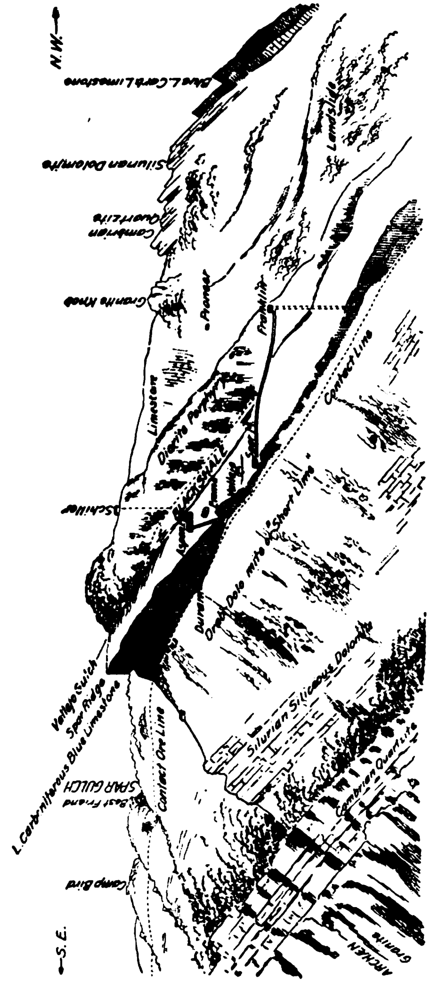


FIG. 9.—NATURAL SECTION OF ASPEN MOUNTAIN, COLORADO, SHOWING GEOLOGICAL RELATIONS AND POSITION OF CAMBRIAN, SILURIAN AND CARBONIFEROUS ROCKS.

into by sheets of porphyry, as in the Ten Mile region at Kokomo.

The "Grits" grade into some coarse maroon sandstones and conglomerates of the Upper Carboniferous, and these into a local transition series of shales and thin limestones, in which the writer discovered near Fairplay, South Park, some fossil insects and leaves recognized as of Permian or Permo-Carboniferous age.

JURA-TRIAS.

These beds are quickly followed by the brick-red conglomerates and sandstones of the Triassic—a series usually over a thousand feet thick, and well represented along the eastern foothills of the range, at the Garden of the Gods, in South Park, at Aspen, and in several other localities. From their prevailing color they are locally known as "Red Beds." They contain no fossils and few ore bodies, though they are often locally impregnated with copper stains.

The Jurassic into which they grade is composed of softer sediments, such as variegated marls, sandstones and some thin beds of limestone. In Colorado only local deposits of ore occur in these, but in California, where they are highly metamorphosed and folded, ore deposits are numerous. In Utah the celebrated Silver Reef sandstone belongs to this Jura-Trias period.

CRETACEOUS.

The deposits of this age attain usually a great thickness, aggregating many thousands of feet, and are divided into four groups.

The Dakota at the base, next the Colorado, then the Montana, and lastly the Laramie.

The Dakota group is characterized by heavy bedded quartzitic sandstone. Near Ouray, in the San Juan region, these sandstones, metamorphosed into quartzite, carry the rich cavernous deposits of the Ouray gold belt. These quartzites are associated with eruptive sheets and dikes of igneous rock.

The Colorado and Montana group consist of shales and limestones. On Treasury Mountain, in the Gunnison region, these shales are metamorphosed by the intrusion of eruptive rocks into roofing slates, and carry local deposits of silver-lead ores.

The Laramie sandstones are more noted for coal than for ore deposits. The rocks of this period contain locally both coal and oil, but in the unaltered strata few or no metallic ores of importance.

TERTIARY.

The Tertiary fresh water sedimentary deposits of sandstones and shales, usually forming great plateaux of nearly horizontal strata, like the Book Cliffs of Western Colorado, are not remarkable ore-carriers, unless, as in the Coast Range of California, they, together with the Cretaceous rocks, have been intensely folded, metamorphosed and penetrated by igneous rocks, under which conditions any kind of rock of any age may be productive of ore.

Although the sedimentary rocks of this geological age are usually barren, the igneous rocks which were poured forth or erupted have been especially ore generating or depositing. The rocks of the Cripple Creek volcano, and the great lava overflows and dikes of the San Juan region, are noteworthy examples. The ore deposits in these igneous rocks may be either in quartz fissures, or the sheets and dikes may themselves be impregnated.

QUATERNARY.

These are the fresh water deposits by ancient lakes and streams or glaciers, and are irregularly distributed over all the other formations.

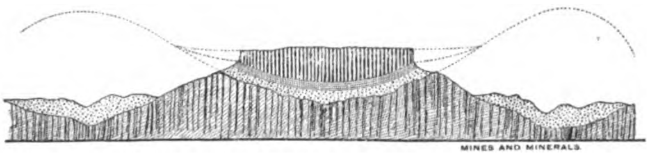


FIG. 10.—ANCIENT GOLD-BEARING RIVER BEDS, TABLE MOUNTAIN, CALIFORNIA.

The gravel and boulder deposits of ancient rivers in California occasionally attain a thickness of nearly a thousand feet, and in these, sometimes overlaid by lava, are the celebrated gold placers of that region, elsewhere described.

In Colorado the surface drift is comparatively shallow, rarely exceeding fifty or sixty feet. It is usually found thickest along the banks of the streams flowing through the mountain cañons, or parks, and yields the Colorado placers, as at Fairplay, Breckenridge, South Park, in the Arkansas Valley near Leadville, and in various other parts of the State.

Throughout Western America the most of the placer beds may be attributed to the streams, lakes and glaciers of the Quaternary period; a few to the more recent rivers, and some to the waves of the present ocean.

Although local elevation of the neighboring mountains may tilt them a few degrees, these deposits are usually horizontal.

For local illustration of the geological periods, as seen in the rocks of Colorado, we may follow the course of any one of our principal streams from its source on the

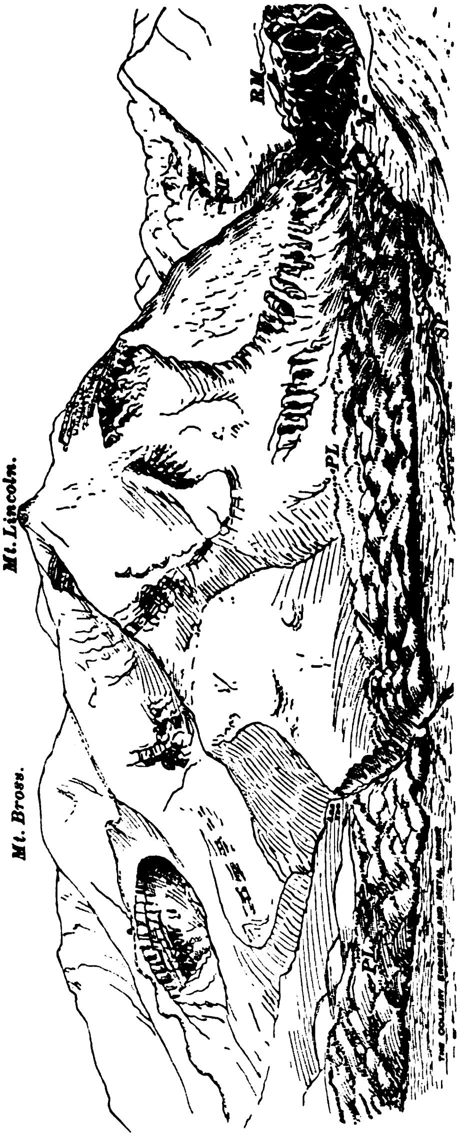


FIG. 11.—GLACIAL MORAINE PLACER BEDS AT HEAD OF SOUTH PLATTE RIVER, COLORADO.

mountain tops down its tortuous cañon till through the foot hills it debouches on the prairie. For some forty or fifty miles the cañon is through granitic rock. The crystalline character of the granite suggests the aqueo-igneous heat to which it has been subjected. Lamination in the schists and signs of bedding in the gneisses are observed. Evidence is shown of intense folding, crumpling, and in the case of schists of intricate puckering and corrugation, implying lateral tangential pressure, such as would result from regional contraction. These granitic rocks were crumpled up into the Colorado front range island above the Paleozoic sea and formed for ages the shore line of seas depositing horizontally the different strata of the Paleozoic and Mesozoic eras. At the close of the Cretaceous or Mesozoic era this was further crumpled upward from an island reef into a mountain range, rising from 10,000 to 14,000 feet above the sea level. This movement must have added new crumples and foldings to the already puckered strata. Heat, due to various causes, partially melted, made plastic and fluid some of the material, which ran into and filled the fissures caused by the uplift. Such were the dikes of eruptive granite and pegmatite found here and there in the granitic complex, as well as molten material from more deep seated sources known as dikes of so-called porphyry or true igneous rocks.

As we emerge from the granite we encounter as we go down the creek, through the foot hills and out on to the prairie, the upturned beds of the various geological periods, commonly resting at steep angles against the flanks of the granite in their geological sequence and order. (See Fig 12, Appendix.)

First come beds of sandstone and limestone, containing a few fossil shells, corals and crustacea, representing the Cambrian and Silurian periods. Next are beds with heavy limestone at the base and coarse sandstone and shale above. In the latter some traces of coal and carboniferous plants mark its age.

Upon this follows a great thickness of coarse conglomerate sandstones, variegated clays, and some limestones of the Jura-trias. The prevailing color has given these the local name of the "Red Beds."

A prominent rampart like ridge or "hogback" next appears capping the soft variegated shales and marls of the upper Jurassic. This is formed of yellow sandstone. It lies at the base of the Cretaceous system in Colorado, and is known as the Dakota group, or Cretaceous No. 1. After passing this "hogback" we generally find an undulating, grassy valley underlaid principally by soft unctuous shales with a few outcrops of limestone. This is the Cretaceous of the Colorado and Montana groups. The next prominent bed of buff sandstone shows fossil remains of sea weed and sea shells. It belongs to the uppermost subgroup of the Montana, known as the Foxhills. But a few feet above this we pass into the sandstones and shales of the Laramie group of the Cretaceous, abounding in impressions of fossil land vegetation, and containing numerous beds of valuable coal.

A few scattered table mountains of coarse sandstone and shales containing numerous fossil leaf impressions, and occasional thin seams of lignite, usually capped by some variety of surface flowing lava, represent our Tertiary on the east side of the front range. On the western slope of the Rockies the Tertiary is developed on a much grander scale, as in the Book Cliffs of Western Colorado, the great Green river and Fort Bridger plateaux in Wyoming, and still farther west by part of the Uinta plateau mountains.

Finally, in Eastern Colorado, on top of all these strata, scattered over "hogback," valley and plain, we find the drift or "wash" pebbles of all kinds of rocks, distributed by the glaciers and floods of the Quatenary.

Since we left the granite shore line at the outlet of the cañon we have passed through and observed not less than 10,000 feet in thickness of the earth's crust, comprising all the geological periods from the Cambrian to the Quaternary and Recent. We have found the strata of all these different periods and epochs upturned and reclining against one another, like leaning rows of books, to the top of the uppermost Cretaceous or Laramie group; and after that the Tertiary strata lying flat, or at a very slight angle. From this we conclude that the strata of all these periods and epochs, accumulated by sea and other waters, lay comparatively undisturbed and horizontal until the close of the Cretaceous, when the granite islands were elevated and assumed mountain forms. Since that time elevation, which is doubtless still going on, appears to have been very gradual.

Such are the general geological features of the foothills and the eastern slope of the Rocky mountains. When unaltered, unmetamorphosed, not penetrated by true ore-bearing igneous rocks they are rarely productive of valuable ore deposits.

When, however, we enter the heart of our ranges into a region like that of South Park, between the front range and the Sawatch, we find its basin underlaid by the same rocks of the same geological periods as in the eastern foothills, but here the folding of rocks was more violent and intense, accompanied by great metamorphic heat and numerous intrusions of igneous rocks. The Cambrian and Carboniferous sandstones are changed into hard vitreous quartzites, limestones in many instances have passed into marble, and in the Gunnison region the coal is transformed into anthracite. A region of such physical characteristics is the natural habitat of ore deposits, and it is here that they are found.

While the general form of the mountain area was sketched out and determined in the earliest geological times, it is only since the Tertiary and, in great measure, by erosion after the glacial epoch that the present sculpturing of the mountain forms with their ravines and cañons has taken place.

CHAPTER II.

LITHOLOGY.

IGNEOUS ROCKS.

These are the originals from which in one way or another all the others have been directly or indirectly derived. They occur in dikes, sheets, laccolites, bosses and vast irregular bodies.

Dikes have come up through fissures in other rocks and solidified in them.

Sheets may be either surface flows which may be afterwards buried beneath sediments, or else forcibly intruded between other strata. If, in the latter case, they are in very thick lenticular bodies tapering out on the edges, they are called "laccolites."

Rough tubular masses chilled in the conduit of a volcano are called "necks." Some large irregular masses between dikes and laccolites are called "stocks."

Irregular projecting rounded bodies are "bosses."

Enormous masses of crystalline rocks, like granites, that in some cases have fused their way upwards by melting into overlying rocks, are called "bathylites."

The character of the occurrence, whether as dike, surface flow, intruded sheet or bathylite, has an important influence on the texture.

As contrasted with the stratified sedimentaries, igneous rocks are massive.

Distinctions have been made between those that have crystallized deep within the earth—the Plutonic, and those that have reached and been poured out on the surface—the Volcanic. The terms intrusive and extrusive or effusive have been similarly employed.

Structure and texture are important considerations, as a massive structure against a stratified one, and a glassy texture against a porphyritic or granitoid. The

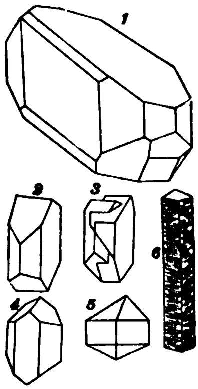


FIG. 15.—BLACK HORNBLENDE AND FELDSPARS.

former is due to rapid, the latter to slow cooling under great pressure. In a magma the least fusible minerals, the feldspars and quartz, are the last to crystallize.

In general, the glassy, felsitic and porphyritic textures pertain to the lavas, or surface flows, the dikes and laccolites, while the granitoid-textured rocks are the deep-seated or abysmal ones. These variations may, however, all shade into one another.

In determining an igneous rock, texture should first be regarded; next the feldspars, as the latter are usually more important than the black minerals; a consideration that may sometimes help is the locality, certain regions being specially characterized by particular classes of rock.

A hand specimen by itself is not always determinable until we know its mode of occurrence in the field.

Granite—The natural history, origin and ore-bearing tendencies of the granitic series have already been discussed under the Archæan and Algonkian periods.

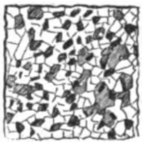


FIG. 14.—GRANITE.

The common constituents of granite are mica, quartz and orthoclase feldspar.

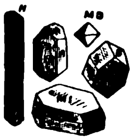


FIG. 13.—HORNBLENDE, AUGITE, MICA, MAGNETITE, GARNET.

If the dark mineral is black mica or biotite, it is called biotite granite or granitite; if the white silvery mica (muscovite) predominates, it is called muscovite granite, such often occurs in dike form, and usually with coarse crystallization; if there is a mixture of biotite and hornblende, it is called hornblende granite. The larger orthoclase feldspars may be accompanied in less degree by small lath-like plagioclase crystals, if these predominate the rock is tending towards a diorite, and may be appropriately called granodiorite. The orthoclase crystals may be pink, red, gray or opaque white. The rock is called a red or a gray granite, mainly according to the prevailing colors of the feldspars. A dark granite results from a preponderance of the dark silicates, biotite or hornblende.

The texture of a granite, whether coarse or fine, is due to the size of its component minerals. A coarse form of granite occurring in dikes or veins, consisting mainly of coarse crystals of feldspar and quartz with little or no mica is called "pegmatite" or, sometimes, graphic granite. when by a peculiar columnar arrangement of the quartz and feldspar on cross section it resembles Hebrew character.

This pegmatite or graphic granite, is the form of granite often associated with ore deposits and locally known

FIG. 16.—PEGMATITE.

as "Quartz vein or reef." Some fissure veins in granite are filled by quartz alone and also carry ores. These pegmatitic bodies, also called binary granites, may be from a few inches to two or three hundred feet in width, and may extend but a few feet, or may traverse the country for thousands of feet. They may run parallel with the bedding planes of the schist or gneiss, or may cut boldly across them. Often there is no line of division between these pegmatitic bodies and the adjacent granite into the substance of which they gradually merge. In other cases the line of demarcation is sharp, like that of a true fissure vein or of an igneous dike. Kemp is doubtful whether to consider these pegmatite masses in the light of veins or of igneous dikes and intrusions. He says: "It seems improbable that true igneous fusion could have afforded such coarsely crystalline aggregates. So we are forced to assume such attendance of steam and other vapors and mineralizers locally as to almost, if not quite, imply solution."

Our so-called quartz fissure veins, carrying the ores are often more strictly a zone of alteration of the country rock along the side or sides of a fissure, than true quartz filled veins.

Pegmatites are the common habitat for a number of non-metalliferous minerals and gems, such as tourmaline, garnets, beryls or epidote. It is in rock of this kind, also associated with large crystals of spodumene and white mica that the tin ores of Dakota are found; and in other parts of the world pegmatite abounding in tourmaline or schorl often accompanies tin.

Granites in which the feldspars are individualized and distinctly set in a somewhat finer ground mass are called porphyritic granites, and may merge into the class of porphyries known as granite porphyries. It may be said here that there is no particular kind of rock called "porphyry." It is a term loosely used and applied by miners to almost any kind of igneous or eruptive rock of a spotted appearance, due usually to the presence of individual or distinct crystals of feldspar. The term poryhyritic is the more correct. Thus, there may be a porphyritic granite, diorite, andesite, rhyolite, or dolerite. The term porphyry, however, has been allowed to remain in this work on account of its long adoption by miners.

By decay or oxidation granites suffer first by the oxidation of protoxide of iron in the ferro-magnesian silicates, biotite and hornblende, forming a soft greenish talcose substance, known as chlorite. The feldspars pass into kaolin or china clay, the so-called miner's "talc" or "gouge" of mineral veins. The insoluble quartz remains or drops out as sand. At the Independence mine, in the Cripple Creek region, the coarse granite at contact with an ore bearing phonolite dike, has, by mineralizing solutions, become reduced to a honeycombed mass with the cavities replaced in some cases by fluorite, secondary quartz, or telluride gold ores.

From the number of gold bearing veins that have been found in granitic rocks in various parts of the world, granite has been called the "Mother of gold."

FIG. 17.—GNEISS.

Gneiss is roughly a bedded granite, or a granite showing more or less distinct signs of bedding. Very massive bedded gneiss is commonly called a granite-gneiss. In these rocks the minerals are frequently aggregated or arranged in lines giving a banded appearance.

FIG. 18.—CONTORTED SCHIST.

Schist might similarly be called a laminated gneiss. The lamina are commonly formed by still closer linear aggregation of the ferro-magnesian minerals, mica, hornblende, etc. Various names are given according to the prevailing mineral composition of the several varieties. Thus there are biotite, muscovite, sericite, mica schists and hornblendic schists.

Although these rocks at times carry precious minerals, deposits in them are often lenticular in form and pockety. This is due to the corrugation of the schists and the quartz lenses following the planes of lamination. If, however, the quartz fissure vein cuts across these planes, the continuity of the vein is more assured.

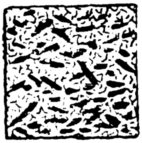


FIG. 19.—SYENITE.

This is a rock nearly allied to granite, but of rarer occurrence in Colorado and the West. Like granite, it appears in dikes and irregular masses. Its composition is crystalline feldspar and hornblende, while mica may or may not be present. In appearance it strongly resembles granite, but is readily distinguished from that rock by the absence of quartz. A typical syenite is an orthoclase feldspar rock with hornblende. A dike of red syenite occurs near the Bull-Domingo mine, at Silver Cliff, Colorado. A syenite occurring in dikes and containing the mineral nepheline is called "Nepheline Syenite." This is found near some of the ore deposits at Cripple Creek. in the heart of the Cripple Creek volcano.

Diorite—This eruptive rock, from its general appearance, is sometimes mistaken for certain kinds of fine-grained granite. It occurs in dikes and intrusive sheets, the latter when very thick are called laccolites. Such diorite laccolites form the lofty La Plata and Elk mountains in Western Colorado, and the Spanish Peaks in the southern part of the State.

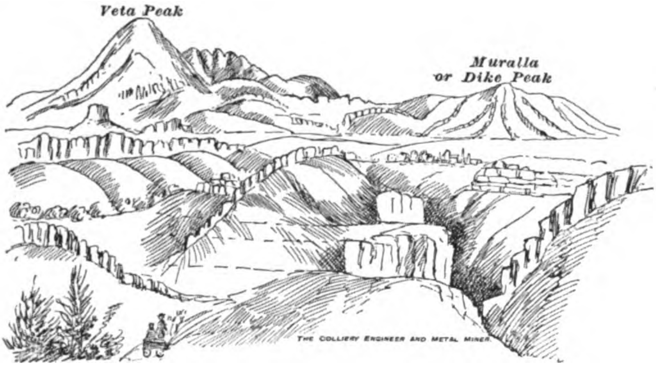


FIG. 20.—DIKES IN SPANISH PEAKS REGION.

Diorites are granitoid rocks, consisting of hornblende, biotite and plagioclase feldspar. When quartz is added they are known as quartz-diorites, and may shade insensibly into granite and be called grano-diorites. The dark minerals alter near the surface to a dull greenish tint, hence the term "greenstone." The plagioclase feldspars are usually small, white or semitransparent, of a lath-like shape, and under the microscope show parallel groovings or striæ.

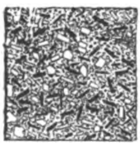


FIG. 21.—PORPHYRITE.

A mottled or spotted rock called by miners "birds-eye porphyry" is usually a phorphyritic diorite or "porphyrite." This porphyrite is often seen in the Leadville and South Park region, intruded in sheets and tongues between the Paleozoic strata. Diorite is a frequent accompaniment of ore deposits in Colorado and the West. Ores may occur at the line of contact between it and other rocks, or in veins in the rock itself. Again, the diorite dike or sheet may be so impregnated with ore minerals as to be workable as a vein; under these conditions the rock is usually much decomposed or altered. The older intrusive Plutonic diorite is akin to its more recent representative andesite.

Porphyries—There is a class of eruptive rocks found in our mining districts, commonly called "porphyry." As stated above, it is a term loosely used and applied by miners to almost any kind of eruptive rock of a spotted

FIG. 22.—FELSITE PORPHYRY.

appearance. A felsite porphyry is a rock composed of a ground mass of orthoclase feldspar, usually fine-grained, or amorphous, in which are set distinct crystals of orthoclase feldspar with the occurrence here and there of a few dark minerals, like mica and hornblende. A quartz-porphyry is practically the same rock with the addition of distinct quartz crystals set in its ground mass.

The Mount Lincoln quartz porphyry of the Leadville and South Park regions of Colorado may be taken as typical. In appearance it is a mottled gray granite-looking rock, spotted over with large crystals of orthoclase sanidin feldspar. Sometimes two of these crystals are locked together, forming what are called Carlsbad twins. (See Fig. 15.) Associated with these are individual double-ended quartz crystals. The larger porphyritic crystals are set in a crystalline ground mass of the same kind; and crystals

FIG. 23.—MOUNT LINCOLN QUARTZ PORPHYRY.

of biotite, mica, and hornblende are freely sprinkled through the mass. This porphyry occurs in dikes and intrusive sheets. It forms the peak of Mount Lincoln. The Leadville white or "block" porphyry is also a quartz

FIG. 24.—LEADVILLE WHITE PORPHYRY.

porphyry, although it rarely shows to the unaided eye its porphyritic quartz crystals. Light colored and shaley, it resembles a shaley quartzite of orthoclase feldspar in which porphyritic crystals of quartz are occasionally set. Several other varieties of quartz-porphyry are found in the Leadville region, such as the gray-porphyry and the pyritiferous-porphyry. These are intimately associated with the lead, silver and gold ores of that region. Mr. Cross has lately grouped all these porphyries under the general term "Porphyrites," in which respect they would seem related to the porphyritic diorites.

Gabbro—Usually a dark granitoid igneous rock, composed of plagioclase feldspar and the dark mineral pyroxene. Gabbros, diorites and the ancient granitoid form of basalt called diabase are all closely allied. All these rocks by alteration of their magnesian minerals are apt to pass into the green substance known as "serpentine." Gabbros and diabases are sometimes found in a volcanic region as dikes in the old granite complex through which the later volcanic rocks were erupted, as at Cripple Creek.

The Spanish Peaks—Among the many striking examples of eruptive rocks in Colorado may be mentioned the Spanish Peaks. Huge laccolites of igneous rock were

FIG. 26.—SPANISH PEAKS FROM LA VETA.

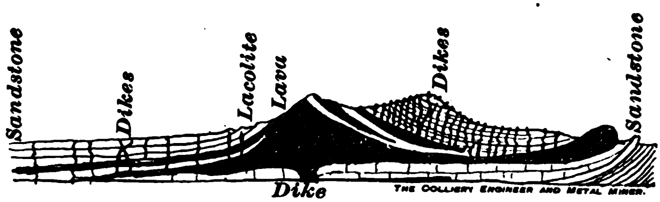


FIG. 27.—CONVERGING DIKES, SPANISH PEAKS, COLORADO.

here intruded into the Cretaceous strata, arching them up. This eruptive disturbance cracked the surrounding country for miles in every direction. Through these cracks or fissures ascended the molten rock and congealed. Erosion followed. The great laccolitic reservoirs were stripped of their sedimentary covering, and sculptured into two of the loftiest and most prominent moun-

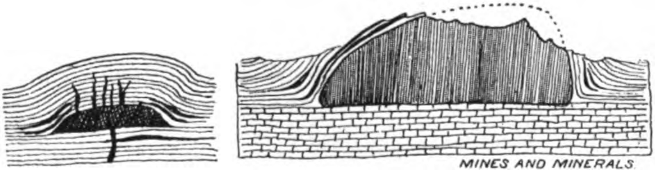


FIG. 28.—LACCOLITIC STRUCTURE, HENRY MOUNTAINS, UTAH.

FIG. 29.—ELK MOUNTAIN LACCOLITE AND HAHN'S PEAK.

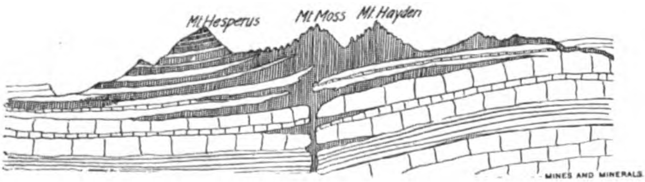


FIG. 30.—LACCOLITE—STRUCTURE OF LA PLATA MOUNTAINS.
(After Holmes.)

tains of Colorado, still further denudation brought to the surface hundreds of igneous dikes standing up above the country like low walls, all radiating from the main center of eruption.

Igneous Rocks in the Mosquito Range—In the deep cañons of the Mosquito Range of South Park it is common to see a narrow dike, issuing from the basal granite,

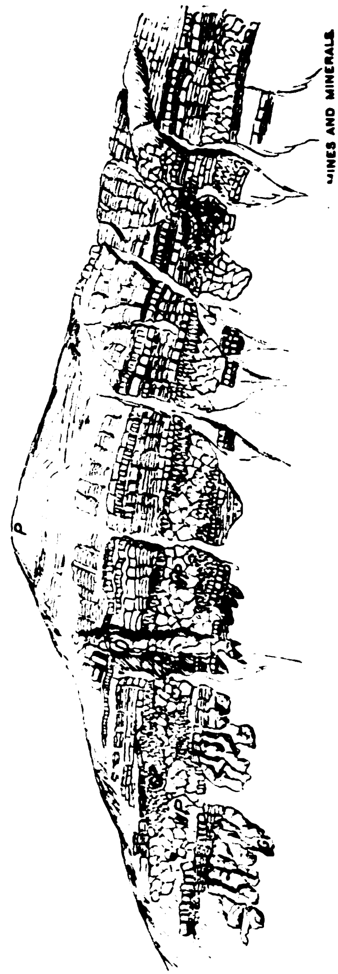


FIG. 31.—NATURAL SECTION OF PART OF MOUNT LINCOLN, SOUTH PARK, COLO.

pass up into and insinuate itself between the bedding planes of the overlying limestone and quartzites. It has opened the strata, faulted them, passed from one bed to another and extended long sheets between the beds, thus clearly showing the intrusive character of the eruption.

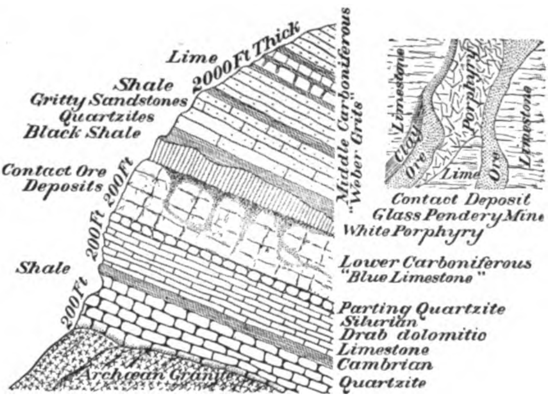


FIG. 32.—SECTION OF LEADVILLE ORE DEPOSITS, MOSQUITO RANGE.

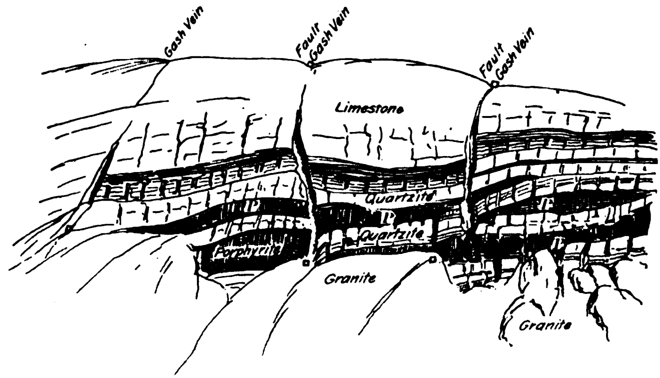


FIG. 33.—GASH VEINS AND INTRUSIVE SHEETS OF PORPHYRITE, BUCKSKIN CANON, MOSQUITO RANGE.

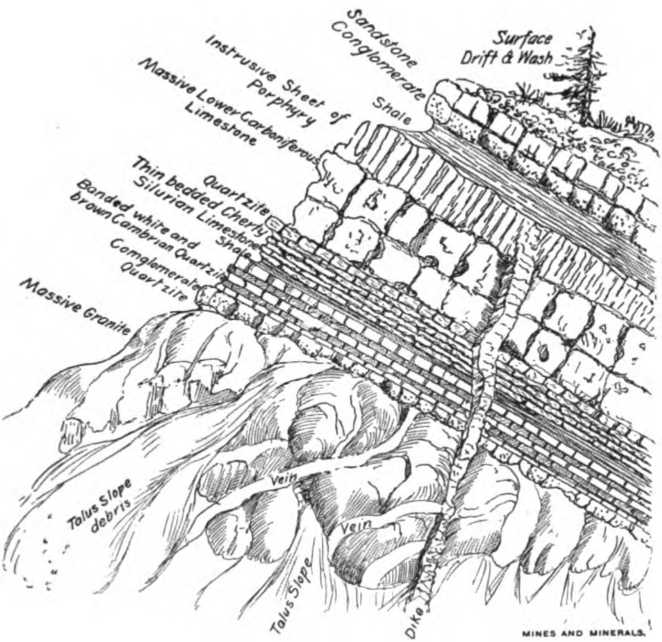


FIG. 34.—IDEAL SECTION LIKE THAT AT LEADVILLE, SHOWING PORPHYRY DIKE, INTRUSIVE SHEET CONTACT AND OTHER FORMS OF ORE DEPOSIT.

Mount Lincoln—Dikes at times may be the cause of the existence of a lofty mountain mass or peak. Mount Lincoln, South Park, rising over fourteen thousand feet above the sea, owes its prominence to dikes of quartz porphyry, which by sending out ramifying, intrusive sheets have bound the sedimentary rocks together as a tree with locking branches, or as with iron girders. These eruptions occurred at different times and intervals, as we find older intrusive sheets cut by newer ones or by more recent dikes.

Ore Deposits—In laccolites fissure veins occur cutting through the igneous mass, as in the La Plata mountains, where fissure veins in the diorite carry telluride gold ores. The intrusive sheet and dike occurrence are particularly favorable to ore deposits at their contact with other rocks, as notably in the Leadville and Aspen mining regions. Ore deposits are also found in the lava flows of effusive igneous eruptions, as in the fissure veins cutting the vast lava sheets of the San Juan region.

An interesting example of a mineralized volcanic neck or filled orifice, is the Bassick Mine of Rosita, Colorado. On a still larger scale are the ore deposits generally of Cripple Creek in the old Cripple Creek Volcano.

Curiously enough craters of modern volcanoes as well as the lavas poured from them are singularly deficient in the precious metals. The same is true of the comparatively recent basaltic lavas capping so many of our table lands in eastern Colorado and New Mexico.

Andesites, etc.—The igneous rocks hitherto described belong to the bathylitic, the Plutonic or intrusive series. Those that follow are mostly of later eruption, and are extrusive or effusive rocks that reached and in many cases poured out over the surface. These are principally—andesites, rhyolites, trachytes, phonolites and basalts.

Andesites are distinguished from the rhyolites and trachytes on the one hand, and from the basalts on the other, by the predominance of soda-lime feldspar.

They are commonly divided into hornblende-andesites, mica-andesites and hypersthene-andesites, according to the predominating ferro-magnesian silicate. Hornblende-andesite is typical. Andesites in appearance are a minutely "pepper and salt" speckled rock, due to the porphyritic character of the compound crystals. The little white specks are soda-lime feldspars, on which striæ may be detected by a microscope, while the prevailing dark

FIG. 35.—VOLCANIC ANDESITE BRECCIA.

mineral is hornblende, augite or mica. An andesite carrying much quartz is called a dacite or quartz-andesite. Andesites and diorites are closely allied in composition, but differ in the mode of occurrence. Diorite is always an intrusive or Plutonic rock. In color andesites may be gray, brown or some shade of red or maroon. From their spotted appearance miners call them porphyries. Besides the massive dikes and flows a common occurrence is that of andesitic breccia, or andesitic tuff; the one composed of large angular fragments of andesite cemented by a lava paste, the other of comminuted fragments cemented into a kind of sandstone. This fragmental form came from explosive vents, and occurred in the form of mud flows.

The greater part of the San Juan region is deeply covered by flows of andesitic breccia and tuff. The fragmental character of these rocks offered many opportunities for impregnation by metalliferous solutions, especially after they had been decomposed by solfataric action. Andesite itself seems to be an ore carrier, especially of gold. In the San Juan region the breccia is penetrated by fissure veins and metalliferous dikes carrying various ores.

Several of the great extinct volcanic cones along the Pacific Coast, such as Mounts Shasta, Hood, Rainier and others, are andesitic volcanoes.

FIG. 36.—RHYOLITE.

Rhyolite—Rhyolites proper are porphyritic rocks. They have large individualized crystals of quartz and orthoclase feldspar, with black crystals of biotite mica and hornblende or augite in a ground mass that is either glassy, or a finely crystalline aggregate of quartz and feldspar, or both. A variety with very little ground mass and an approximation to granitoid texture is called nevadite, from the state of Nevada. From quick cooling, rhyolites may pass into a dark vitreous rock called pitchstone or pearlstone, not unlike obsidian. In common with all effusive rocks poured out from explosive vents, there are rhyolitic breccias and tuffs. In color rhyolite is more often light than dark. It is common in Colorado and the West, and formerly went by the name of the much rarer rock trachyte. Generally speaking, it is not so productive of the precious metals as andesite or diorite; mines, however, at Creede, (Colorado,) at Mercur, (Utah,) and at Delamar, (Idaho,) are in rhyolite.

Trachyte—This rock closely resembles rhyolite. Its principal mineral is a sanidine orthoclase feldspar. The black minerals may be mica, hornblende or augite. The ground mass is glassy. This rock is not common in Colorado or the West. It occurs locally at Silver Cliff, Cripple

Creek, and in South Park near Fairplay, but not there associated with ore deposits.

FIG. 37.—MICROSCOPIC SECTION OF BASALT, SHOWING SERPENTIZATION OF LARGE CRYSTAL OF OLIVINE.

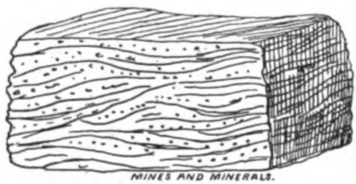


FIG. 38.—PHONOLITE.

Phonolite—Is chemically an essentially alkaline rock, nearly all its component minerals being alkaline. Phonolites break up in thin plates, which under the hammer give a ringing sound, hence the name. The color is usually dull drab or gray. The principal minerals are sanadine feldspar, and nepheline or leucite or both. The dark silicates are the soda pyroxenes, acmite and ægirine. Hornblende is occasionally seen. The rocks have usually a compact gray or greenish ground mass in which are visible shining sanidines, seldom nepheline and rarely dark rods of pyroxene. Phonolites are at present known only in a few localities in this country, notably at Cripple Creek, Colorado, and the Black Hills, Dakota. They occur at Cripple Creek in dikes and intrusive sheets cutting through the overlying andesite breccia, and are intimately associated with the telluride gold ore bodies. Ore deposits may occur in quartz fissure veins in the dikes, or at contact of the dikes and breccia or granite, or the dikes themselves may be impregnated with mineral.

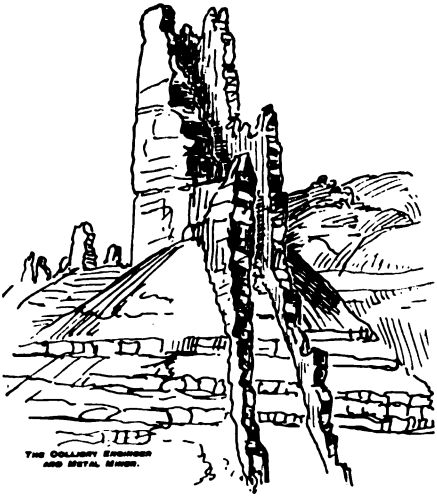


FIG. 39.—DOUBLE DIKES OF BASALT, SAN JUAN.

Basalts—These are heavy dark basic rocks, usually porphyritic, but at times cryptocrystalline. The chief minerals are plagioclase feldspar, augite, olivine and magnetite. The ground mass is a finely crystalline aggregate of these. Coarsely crystalline basalts are called dolerites. A granitoid form of basalt usually of older date is called diabase. In diabase the feldspars are in long narrow crystals. In the interstices between the lath-shaped crystals are found dark silicates and magnet-

FIG. 40.—DIKES CUTTING STRATIFIED BEDS OF TUFF, MOUNT VESUVIUS.

ite. The basalts, especially those of more recent date of eruption, are, generally speaking, not notable as ore producers.

In the Trade-Dollar Mine of the DeLamar District of Nevada the fissure veins in rhyolite and basalt carry

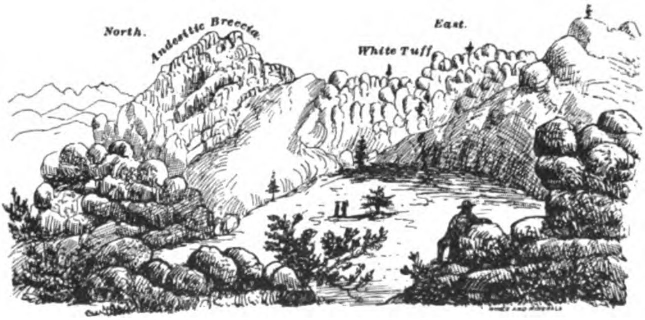


FIG. 41.—OLD ANDESITE CRATER, SALIDA.

the ore, and the older diabases are not infrequently associated with ore bodies. A variety of basalt known as nepheline-basalt is a prolific source of ore in the Cripple Creek district, where it occurs in dikes.

The basaltic caps which cover so many of our table lands in the West, as well as those basalts erupted from modern volcanoes, are commonly barren of ore.

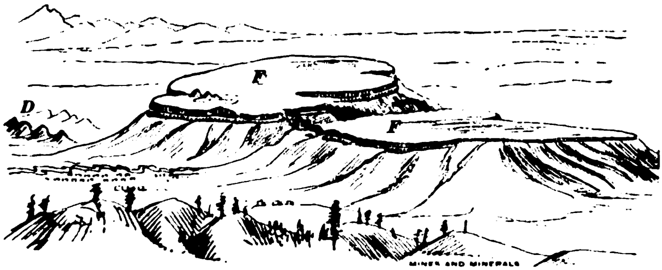


FIG. 42.—LAVA-CAPPED TABLE MOUNTAIN, GOLDEN, COLO.

CHAPTER III.

CAVITIES AND OTHER WEAK PLACES.

Since ore and vein matter are deposited in some kind of opening or weak place in the rocks, it is well before discussing veins and ore deposits, to consider what these openings are, how formed, and where and under what conditions they may be expected.

In contraction caused by cooling, drying and hardening, both igneous and sedimentary rocks break into more or less regular masses along division planes, called joints. Numerous cracks and small cavities are thus formed.

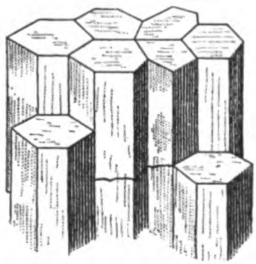


FIG. 43.—JOINTS IN COLUMNAR BASALT.

Basaltic lava and some other igneous rocks on cooling split up into a more or less regular system of contraction cracks, dividing the sheet into the well known columnar structure; these cracks are sometimes filled with calcspar or zeolite minerals forming veins. Granitic rocks and porphyries break into less regular masses and on a larger and profounder scale. The joint cracks descend often to very great depths. These are notable pathways for solutions carrying vein material, quartz or feldspar, and with them at times the precious metals or ores. (Figs. 44, 49.)

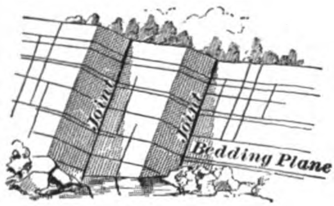


FIG. 44.

Joints also traverse rocks of sedimentary origin, cutting through all the beds and acting as conduits for ore-bearing or mineral solutions, these joints are due to drying and consolidation and sometimes it may be to earthquakes. "The strains," says Kemp, "induced by the compression on the outer portion of the earth, are the most important causes of fracture. The compression

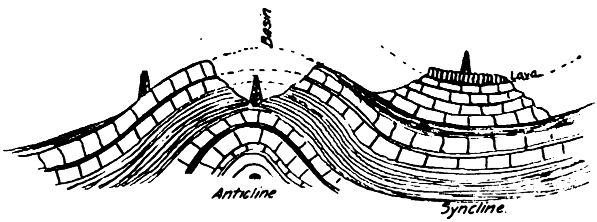


FIG. 45.—ANTICLINAL AND SYNCLINAL FOLDS.

develops a tangential stress which is resisted by the arch like disposition of the crust. Where there is insufficient support, gravity causes a sagging of the material into synclinal troughs or basins, which leaves salient anticlinals (Fig. 48) and corresponding basins between them. (Figs. 45, 46.)

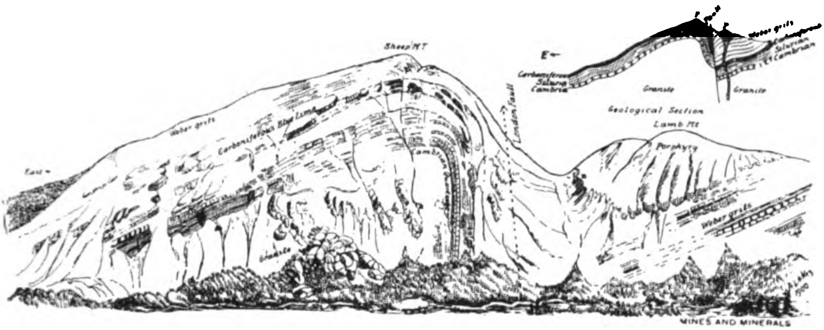


FIG. 46.—SHEEP MOUNTAIN, ANTICLINAL FOLD, AND LONDON FAULT, MOSQUITO RANGE, COLORADO.

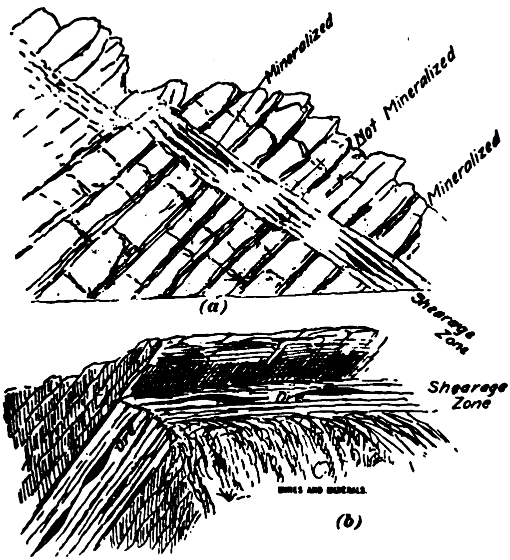


FIG. 47.—VEINS IN SHEARAGE ZONES.

Where the tangential strain is very strong the rocks are crumpled into folds from the thrust. These folds break, causing faults, fissures and general shattering. If the rocks are firm and heavily bedded like some limestones, the fissure is clearly cut; if they are softer and more pliable, they are sheared downward on the stationary or lifting side and upward on the one which relatively sinks. Such fault fissures may pass into folds along their strike, as at Leadville, Colorado.

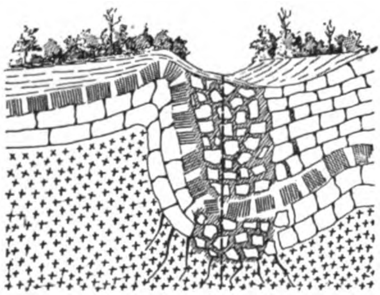


FIG. 48.—FOLD SHOWING BROKEN CHARACTER OF FISSURE AND ADJACENT ROCKS, PRODUCING LATER A BRECCIATED VEIN AND HORSES.

In metamorphic regions what are called shear zones may be made apparent by changes in mineralogical composition and structure. Massive diabase by shearing may pass into hornblende schists for limited stretches, garnets and other metamorphic minerals appear, pyroxenes alter to amphiboles, and even the minerals themselves are drawn out, flattened and sheared. These crushed strips or shear zones may result from very slight displacements, but they form favorable zones for the deposition of ore bodies, as in the Gold Coin Mine at Victor, Colorado, in shear zones in the granite of Squaw

Mountain, and in many of the phonolite and nepheline basalt dikes of Cripple Creek, which are so productive of telluride ores. These dikes are sheared almost into slates by multiple fissures parallel to their bounding walls. Anticlines and synclines cause great disturbance. Rocks cannot bend beyond a certain point without breaking, the result is a series of fractures or fissures radiating from the axes of these points of disturbance. Ore deposits may collect in these fissures as in the zinc-lead deposits of the Mississippi Valley." Such fissures may show no displacement and give rise to gash veins.

FIG. 49.—ILLUSTRATING GASH VEINS IN JOINTED ROCKS.

When sedimentary beds have been laid along an older axis of granite, or some equally resisting rock, and the thrust crowds the beds against the axis, the conditions are commonly favorable for great fractures and disturbance, as in the foothills of the Rocky Mountains. This crowding of sedimentary rocks against an unyielding granite mass may be further intensified by the uplift of a younger range at no great distance from an older, as in the region along the Roaring Fork, near Aspen, Colorado, where the younger volcanic range of the Elk Mountains has crowded and crushed the intervening sedimentaries against the older unyielding mass of the Sawatch Mountains, resulting in a region of intense folding and corresponding faulting with ore deposition.

Lines of weakness may be established from an early period and become the locus of faulting even up to the

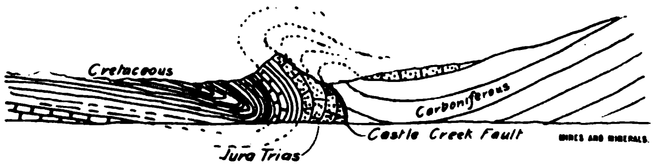


FIG. 50.—REVERSED FOLD, QUEENS BUTTE, ASPEN.

present time. On the western front of the Wasatch Mountains in Utah is a great line of weakness that was first faulted in Archæan times and has suffered disturbance even down to the present. The line of this fault is indicated by a series of hot springs, extending at intervals along the base of the range. Movements along this line have been recorded within the human period. Similar movements seem in progress in parts of the Rocky Mountains in Colorado, where modern land slides are along the lines of more ancient ones.

Fault fissures occur also in igneous rocks. The Comstock Lode fissure in igneous rocks is four miles long and the vertical displacement is three thousand feet. Such great fissures are usually accompanied by numerous minor parallel fissures, all of which may become pathways for ore solutions. It is not uncommon in regions like the San Juan, traversed by numerous parallel fissure veins, to find one, from its size and length called the "Mother Vein," accompanied by a series of smaller parallel veins on either side.

The eruption of igneous dikes and laccolitic intrusions may cause fissures radiating from the center of disturbance, as in the case of the Spanish Peaks (Fig. 25), the laccolitic mountains of Southern Colorado. Hundreds of dike filled fissures radiate in all directions over the surrounding country, some of which extend twenty or thirty miles from these centers. The same is true of the laccolitic region of the Elk Mountains in western Colorado, where numerous fissures filled with ore bodies have resulted, as at Aspen and Crested Butte.

"Chemical action assists both in forming and enlarging cavities and weak places and filling them with vein matter. Water by its carbonic acid dissolves

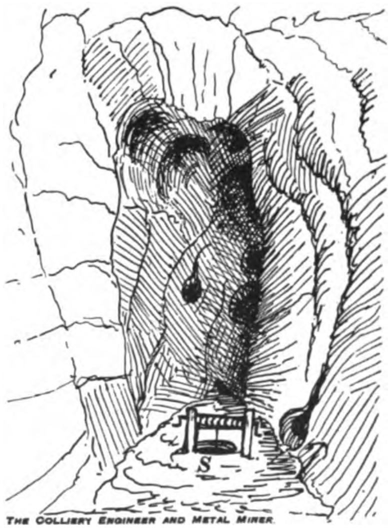


FIG. 51.—"CAVE" ORE DEPOSITS, JEDD MINE, SAN JUAN.

rocks and enlarges cavities. When this water descends to great depths, and becomes heated under great pressure, its action is increased. It takes into solution all the vein making minerals it finds in the rocks. Alkaline carbonates and sulphides are formed, silica is dissolved for veinstone, and the various metals enter into solution in the heated alkaline waters. The action on the walls of cavities formed by faulting movements is great, hence their decomposed and irregular cavernous outlines."

"Again, the process known as dolomization is a potent factor in weakening rocks, opening small cavities and interstices and so giving access to vein and ore solutions. Magnesia is an alkaline earth, readily taken into solution by carbonated waters. When this encounters limestone it effects a partial molecular exchange with the lime carbonate leaving the rock a double carbonate of calcium and magnesium, or a dolomite. The irregularity in the molecular exchange in volume causes a general shrinkage of the limestone resulting in a shattered porous condition, as at Aspen, Colorado, where the Carboniferous limestone is in part dolomized, and the rock broken up into little cubes cemented by ore and vein matter to

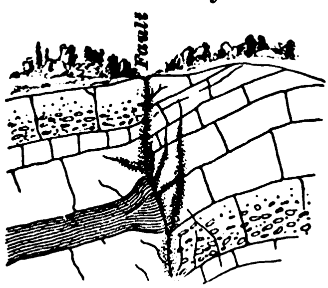


FIG. 52.—ORE DEPOSITS IN CRUSHED ZONE ADJACENT TO A FAULT.

such an extent that the dolomite is known to the miners as 'short' lime. Such a shattered zone is ideal for replacement by ore and vein matter. This is so well recognized at Aspen that the line of demarcation between the zone of dolomization and the unaltered limestone is called the 'mineral contact.'" (Fig. 9.)

The molecular replacement or interchange of metallic mineral with limestone or dolomite is called a metasomatic interchange, substitution or replacement.

Alteration of the metallic ores may also produce cavities or weak zones and make way for a substitution or replacement by other or fresh ores.

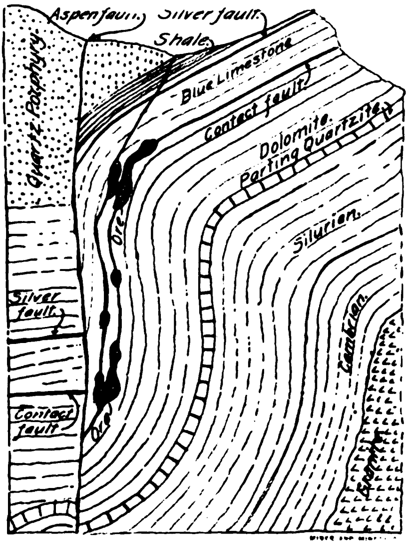


FIG. 53.—ORE OCCUPYING LINES OF SHEARAGE FAULTS AT ASPEN.

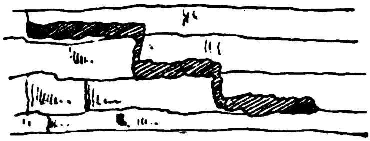


FIG. 54.—ORE FOLLOWING JOINTS AND STRATIFICATION PLANES.

Lines of weakness and cavities occur along the planes of faults, and particularly at their points of intersection with cross faults. These, as at Aspen, are favorite places for ore deposition. (Fig. 53.) Another favorite

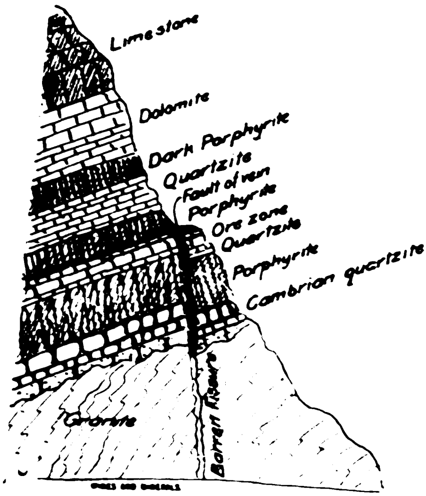


FIG. 55.—EXAMPLE OF ORE BODY IN FAULT PLANE, MOSQUITO CANON.

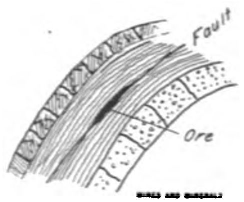


FIG. 56.—FAULT AND ORE FOLLOWING BEDDING PLANE.

place for invasion by ore solutions and depositions of mineral is along the bedding planes or lines of separation between the strata. In some cases this natural division by a pause in sedimentation may have become also a line of actual fissuring, one stratum by thrust movement having slid upon or along the face of the other. Such a movement would be indicated by slickened walls, breccia, etc., instead of a so-called bedded vein there would be a true fissure vein. Such is often the case at Aspen, where

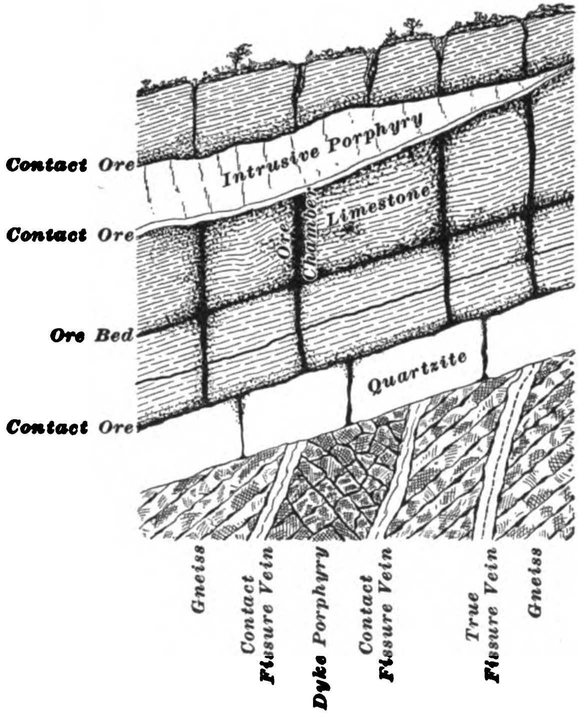


FIG. 57.—SECTION SHOWING CONTACT ORE DEPOSITS.

the fault plane for a certain distance nearly or quite coincides with the natural bedding plane.

Joint planes either above or below the bedding planes where they cross them form conduits for ascending or descending ore solutions, and ore is deposited more especially at the line of crossing or along the bedding plane. Contact deposits are formed in a similar way at the line of contact or separation between two dissimilar strata or between two dissimilar rocks, as quartzite and limestone, or porphyry and limestone. (Fig. 57.)

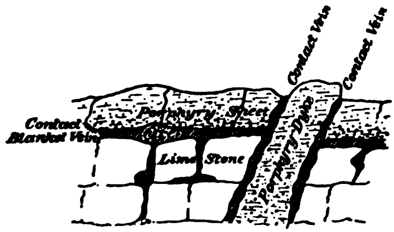


FIG. 58.—ILLUSTRATING CONTACT VEINS.

Volcanic eruptions of various kinds and forms produce cavities, fissures and weak zones fitted for attack and circulation of ore bearing solutions. Volcanic vents or throats of old craters filled with a loosely cemented agglomerate of boulders are of this nature, as at the Bassick Mine at Rosita, Colorado. In these cases the cementing material, not the substance of the boulders, is what carries or is replaced by ore. Even in these agglomerated masses there may be a fissuring system more or less determining the course of the principal ore shoots. At the Bull Domingo Mine, in the same region as the Bassick, the arrangement of the galena coated granite boulders is along the line or at the junction of a series of radiating fissures.

CHAPTER IV.

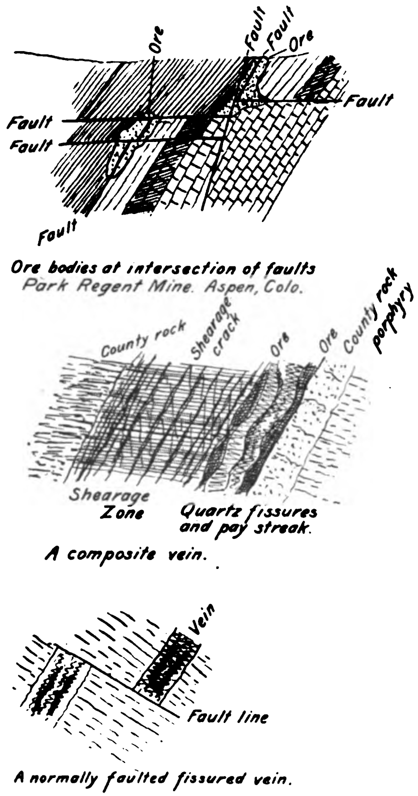
FAULTS.

"A fault may show itself only by a mass of broken material, or by a sharp clear cut, which may be very short or extend for many miles, as in a modern case in New Zealand, where an earthquake of 1845 produced a fissure averaging only eighteen inches in width, but traceable for a distance of sixty miles parallel to the axis of the mountain range."

R. H. Stretch says: "A fissure, whether long or short, must terminate somewhere, and the grinding motion preparing a fissure for the subsequent filling by a vein must be greatest where the displacement of the walls has been most extensive and die out to nothing at either end." Hence it is that we sometimes find the main width and main zone of ore deposition near the middle of a fissured zone, because the central portion was the natural course of easiest circulation of water and ore solutions. At either end the deposit is likely to be barren or to play out.

In sedimentary strata which rest on a granite base, small local faults are sometimes observed. It would seem as if these faults, which usually terminate at the junction with the granite, had been caused by the strata being, so to speak, shaken up on top of the granite. Such faults, when filled by ore, are called gash veins. Examples of such veins are found in some of the mines of Buckskin Cañon, South Park. (Fig. 33.)

A fault may cut the rock formations, either at right angles to the strike, or it may run parallel with the strike and cut down either following and conformable with the



MINES AND MINERALS.

FIG. 59.—SOME FAULT PHENOMENA IN MINES.

bedding of the strata, or it may cut across diagonally at a very acute angle, or be more nearly vertical than the dip of the strata. Veins occupying such strike fault planes have not infrequently been mistaken for, and called, "bedded veins," or, if they lie conformably between two different kinds of rock, "contact bedded veins." The fact is, they are true fissure veins occupying a distinct fissure, as evidenced by the polished striated faces of the strata or walls enclosing the ore

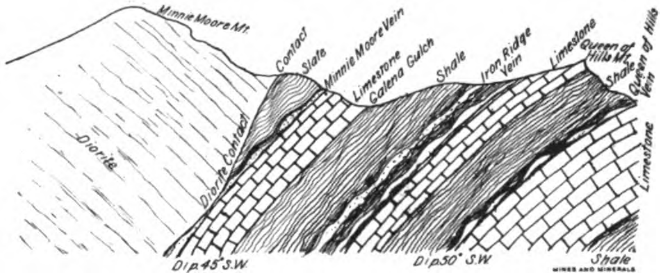


FIG. 60.—ORE DEPOSITS, MINNIE MOORE MINE, IDAHO.

deposits, as well as by the occurrence of fault breccia.

Such conditions frequently appear in ore deposits in regions of highly tilted slates or metamorphosed shales, as in the Minnie Moore Mine, of Bellevue, Idaho.

The line of a fault fracture, both along its surface outcrop and its downward course, may vary greatly, according to the different physical characteristics of the rocks it penetrates. While passing through a massive

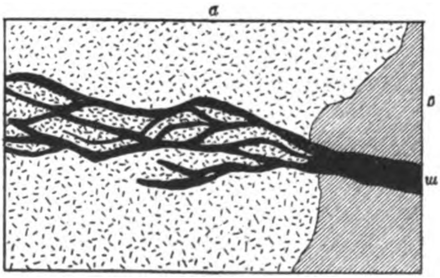


FIG. 61.—VEIN SPLITTING UP INTO BRANCHES ON PASSING FROM SLATE INTO PORPHYRY.

rock like limestone, the fracture may be originally clear, sharp-cut and narrow, but subsequently greatly widened by erosion and dissolving of the lime. On entering pliable strata like slates the fissure is liable to break up in a zone of many small fractures. In a loose, open rock, like a coarse conglomerate, the fracture may be in the form of a large zone of breccia. (Fig. 62.)

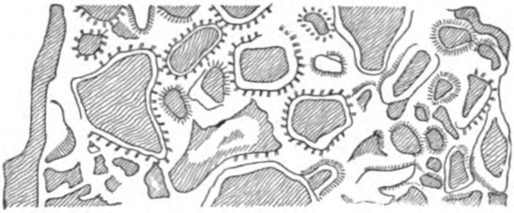


FIG. 62.—BRECCIATED VEIN WITH COCKADE ORES.

A fissure vein on the steep slope of a hill, running parallel with the strike, is likely to be faulted in a series of step faults, giving, by a series of repeated outcrops, the impression that there are several parallel fissure veins in the hill instead of a repetition of one single vein by faulting. A lack of knowledge or recognition of this fact has led at times to long and expensive crosscuts in search of the veins apparently indicated by the surface outcropping.

Irregularities on the plane of fault fractures, both along the strike and downwards, give rise to alternate pinches and pockets, for in steeply dipping shales slates or schistose rocks, strike faults are liable to have large cavities, both along the strike and downwards, from a buckling of the pliable strata, as by a compressive force exerted laterally.

These buckles often carry the largest ore pockets, and, as in the Minnie Moore Mine of Idaho, the buckle and ore pocket may be traced down from level to level.

"Before veins could be formed and filled there must have been fracturing of the rocks to admit circulation of waters, and the nature of the fissures thus produced is influenced by the varying hardness, brittleness or solubility of the rocks fractured, as well as by the direction in which the forces may have been applied. Veins in the same classes of rock and formed at the same time in a

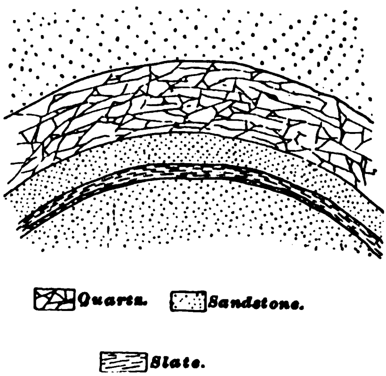


FIG. 63.—SADDLE REEF STRUCTURE.

given region are apt to have much in common, both in structure and contents."

"Besides absolute faulting or dislocation of the rocks to afford openings for vein formation simple folding of the strata may have been sufficient to form zones of weakness for saturation by ore-bearing solutions without actual displacement." (Kemp.)

Not all fault fractures in a mountain system are filled by vein material or ore. For example, the faults at Leadville are, for the most part, notoriously barren. Again, though a region be split up by a system of parallel fractures, and though all these be filled by quartz or gangue matter, they may not all be ore bearing, still less profitable. It is by no means uncommon to find great veins of barren or "bull quartz" parallel to and not far from smaller veins prolific in ore. In some districts the mineralization by ore appears to be related to the proximity of eruptive dikes. Away from these dikes the vein fissures may be barren.

Faulting and Re-Opening of Fissure Veins.—In addition to the general faulting of the strata containing ore deposits, fissure veins which occupy permanently a fault fissure are themselves liable to faulting by a more recent fault, or by a more recent vein occupying a later fault fissure.

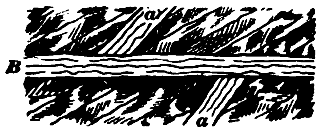


FIG. 64.—VEIN FAULTED BY CROSS VEIN.

In this case the older vein is said to be "heaved" by the newer vein. Sometimes a fissure vein is faulted by a later fault whose fissure is not filled by vein matter. This is called, in Cornwall, a cross course. Then the fissure vein may be dislocated, or perhaps broken two or three times, like a stick broken by a lateral thrust, each break shifting part of the vein more and more to one side of the original downward direction or line of the fissure. Unlike faults in a coal mine, where the lost coal seam is sought above or below, the metal miner seeks his lost vein to right or left of him.

Again, in a given region there may be two distinct systems of veins, having two distinct strikes, the one bearing either at right angles or diagonally to the other. The younger system may fault the older whenever they cross, or, if the strikes are not widely different, and they meet at an acute angle, one vein may, for a distance, slide along by the side of the other, almost making one wide vein, until they cross without any apparent dislocation and continue their several courses. When a group of veins has been made at the same time by a star-like fracturing of the country there is no heaving or faulting of the veins, but they simply radiate from a given center. This is not infrequently seen in the San Juan region, and there, as under these conditons generally, the vein contents are likely to be similar.

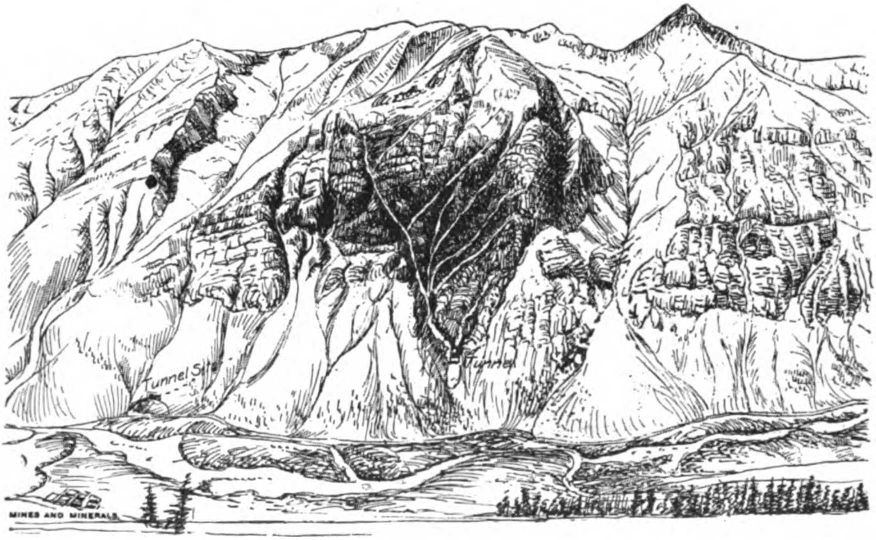


FIG. 65.—QUARTZ VEINS BRANCHING FROM MASTER VEIN, HOWARDSVILLE, SAN JUAN MOUNTAINS, COLORADO.

The re-opening of fissure veins and the filling them with newer material in combs or bands of vein matter and ore also belongs to the same principle of faulting and fissuring. The vein, being a healed wound in the rocks, is a line of weakness particularly subject to attack, movement, re-opening or fissuring when any later mountain movement takes place. Besides the introduction of fresh vein matter, and it may be different minerals, into the original vein, the line of secondary fissuring is often

FIG. 66.—COMPOSITE FISSURE VEIN, CROESUS MINE, IDAHO.

marked by gouge or selvage matter in the heart of the vein.

Composite veins made up partly of a main fissure, and numerous mineralized slips, cross slips and shattered rock belong to the shearage zone system. This is a modified form of faulting due to compression or stress. Such composite veins are common at Butte, Montana, at Rossland and Cœur d'Alene, and in the Crœsus and some other gold mines near Hailey, Idaho.

These composite shearage zones of multiple fracture appear to offer better opportunities for wide mineralization and large bodies of ore than a single fissure occupied by a normal fissure vein. The main fault fissure, or principal fracture, is often filled by a conspicuous quartz vein, having all the appearance of a true fissure vein. This usually carries the pay streak. Alongside of this a zone of country rock, split up by minute fractures and parallel slipping planes, may be mineralized with ore, mostly low grade.

Faults of the Leadville and South Park Region.—Fissure veins, as well as blanket or bedded deposits, are oftentimes faulted together with the strata or rock enclosing them. Fault fissures, too, are the natural habitat for many veins and ore deposits. The common rule in faulting is that the footwall of the fault fissure rises or remains constant while the hanging wall drops down.

FIG. 67.—REVERSED FOLD AND FAULT. ORE BODY IN PLANE OF FAULT.

When the opposite to this occurs it is called a reverse fault. The ends of the strata that may contain a bedded ore deposit on the footwall side of the fault fissure in a

FIG. 68.—FOLDING AND FAULTING OF MOSQUITO RANGE.

normal fault are commonly found bent downward, as if dragged down by the fallen hanging wall side, then the ore deposit may be looked for below. However, the opposite is sometimes the case.

A faulted region is one in which great folding, or crumpling, of the rocks has taken place. This is due to horizontal, lateral or tangential pressure and strain. When the folding reaches its utmost tension the rock breaks and a slip or fault is the result. (Fig. 68.)

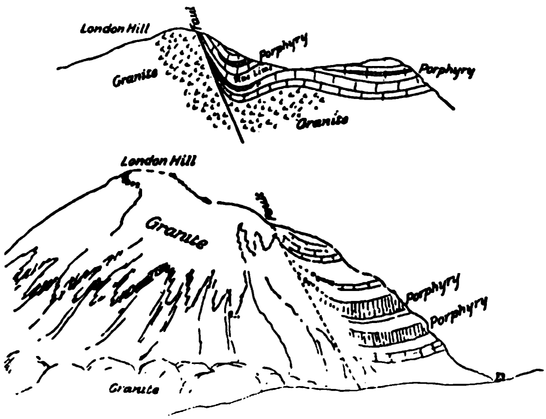


FIG. 69.—LONDON MINE FAULT, MOSQUITO RANGE, COLO.

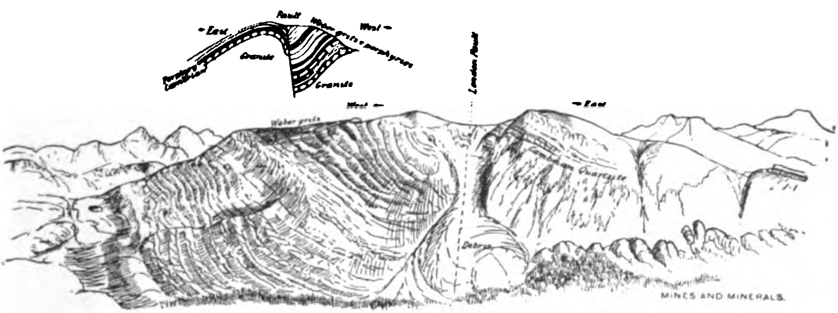


FIG. 70.—LONDON FAULT, MOSQUITO RANGE, COLO.

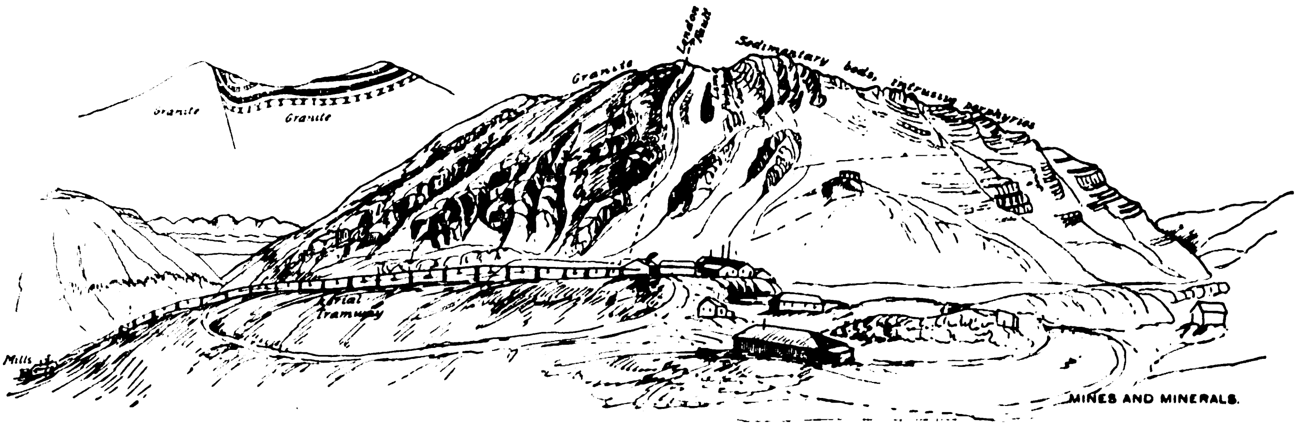


FIG. 71.—LONDON MINE AND FAULT, SOUTH PARK, COLO.

In the South Park region, adjacent to Leadville, the horizontal strata of the Park Basin, as they approach the Mosquito Range, become folded. The folds increase in closeness and steepness as they near the range, until, as we enter Four Mile Cañon, which gives a complete cross section of the mountains, the axis of the range is seen to be formed by a magnificent arch, which breaks down abruptly on the steepest side into the great London fault. This fault runs along and splits the range for more than twenty miles. Still further into the range towards Leadville, is a series of parallel faults, each representing a fold that once preceded the faulting. Following the course

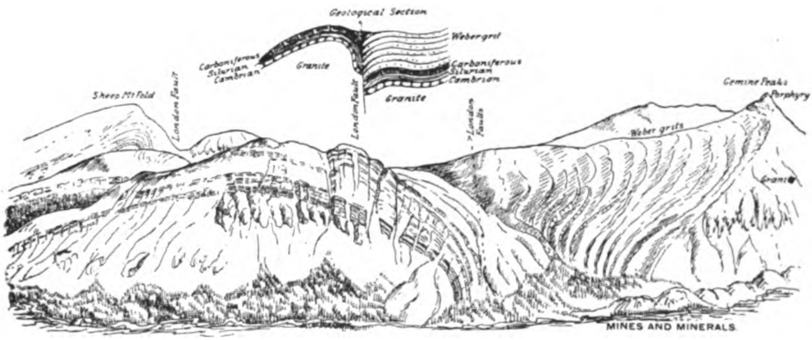


FIG. 72.—FOLD AND FAULT, SACRAMENTO ARCH, MOSQUITO RANGE.

of the London fault from its inception, in Round Mountain on the south, where it dies out at that end, the fault is shown in each successive cañon intersecting the range, in one it is at the side of a steep arch, in another the top of the arch has been removed, and the ends of the strata stand up abruptly; again it is at the side of a low, broad arch, as in Little Sacramento Cañon. (Fig. 72.) In Big Sacramento there is no sign of any arch that has

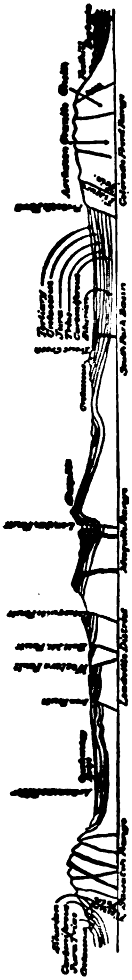


FIG. 73.—SECTION OF LEADVILLE REGION.

been removed by erosion. The line of fault is seen in a ravine down the side of the cliff, and is filled by great masses of debris. Across the hill, in Mosquito Cañon, the fault is shown by Paleozoic strata abutting against a solid mountain of granite. The dying out of the fault, north, is lost in the chaos of mountains, but it doubtless ends in a fold. (Figs. 69, 70, 71, 72.)

Surface and Other Indications of Faults.—The surface indication of faulting is sometimes a sag or a sudden depression in the outline of a hill. Thus, from the Mosquito Range, we descend to Leadville on the west side by a series of Cyclopean steps or benches, the line of each fault being very markedly a sag on the hill slope, the depression often constituting a little ravine filled by a water course and abounding in vegetation.

Sometimes the line of a fault may be followed for a distance along the surface by the outcropping of a comb of rock whose strike is different from that of the surrounding strata.

In a mine fault movements are indicated by slicken-sided, polished and grooved faces of the walls, by a general broken-up character of one or both walls, by a zone of broken rock, down which water may drip copiously, also by fault breccia or small broken fragments of rock, due to the grinding of the walls in the process of slipping. This breccia may be cemented by calcspar, or even by ore. The grinding process may, as in the Comstock fissure, reduce the quartz to a powder like commercial salt. The polished or slicken-sided faces of the walls often show groovings or striæ, which may indicate the direction of the slipping motion. In some cases this motion may be nearly vertical, in others transverse, lateral or horizontal, and again twisted, as if by a torsional strain, due to a greater displacement in one part of the fissure than in another. The strain caused by faulting sometimes leaves the faces of the slips in such a state of tension that when the pressure is relieved they scale off with a slight explosion. These motions were probably slow, or by short jerks, at times accompanied by earthquake shocks rising to the surface.

Measuring a Fault—In a good section of a cliff, as is sometimes afforded in our deep cañons, by observing some well defined or peculiar rock or stratum high up on the face of the cliff, and a corresponding one further down, we may easily compute the amount of slip or dislocation. When, however, faults amount to thousands of feet of displacement it is only by an accurate knowledge of the geological position of the displaced members that we can form an estimate of the amount of slip. If, for example, the Cambrian series at the base of the geological scale is brought up in juxtaposition with the Tertiary, we know that there has been a movement of several thousands of feet to bring these two widely distant rocks on the same line. On Castle Creek, near Aspen, the thick Mesozoic Red Beds lie at the bottom of the creek at the base of a steep lofty cliff of granite, on top of which rest the Paleozoic limestones and quartzites forming the crest of Aspen Mountain, a great fault has taken place by which the Paleozoic strata have been lifted up and the Mesozoic correspondingly depressed.

The downward direction of a fault plane or fissure is more often slanting than vertical. It may vary in degree of dip, or descend by "steeps and flats." Its strike across the country is not always straight, but often curved, sinuous, or zig-zag. In a faulted district like that of Leadville there is usually a prevailing direction of upthrow or downthrow. At Leadville the upthrow is to the east, and the footwall of the fault fissure is the eastern, while the hanging wall or western face of the fissure has fallen. The greatest amount of slip here amounts, near the center of the district, to some thousands of feet. The slip diminishes north and south and dies out in folds represented by rounded hills.

The exact line of the fault fissure is usually obscured on the surface by debris, crushed rock and vegetation. In the mines with depth we may find both walls wedged tightly together and one side or both much crushed. Sometimes a little mineral may be found on the "cheeks" of the fault, dragged down from ore bearing strata above or leached from them and redeposited.

The fissure of the Iron fault at Leadville in the McKeon shaft is three feet wide in places and filled with broken rock and a dark clay. The "cheeks" are altered by surface waters impregnated with iron oxide, and what ore there is is water-worn. The outcrop of the fault on the surface is irregular. Its direction downwards is steep, but accompanied at intervals by benches on which are rich deposits of ore. The main fault is attended by a series of smaller faults parallel with and adjacent to it. From the movement of timbers, of five degrees or more in some of the mines adjacent to the fault plane, it is inferred that the fault movement is still continuing. Similar movements have been observed in the Centennial mine at Georgetown and in some of the mines at Aspen.

Faults of the Aspen Region—The Aspen mining region of Colorado is one peculiarly broken up by a multiplicity and great variety of faults, they have an important relation to the deposition of the ore bodies, as the latter are commonly along the planes of the faults, or at their points of intersection with one another. In this region almost every kind of a fault is represented. There are normal step faults and abnormal or extraordinary reversed faults. There are slipping faults along and par-

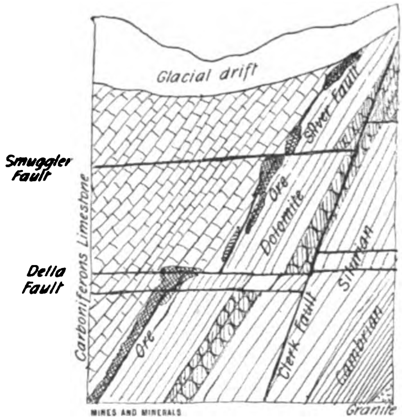


FIG. 74.—VEINS AND FAULTS AT ASPEN.

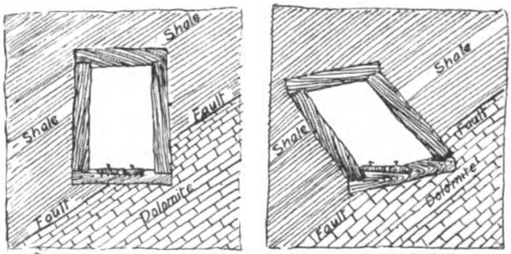


FIG. 75.—SHAFT TIMBERS DEFORMED BY SLIPPING OF FAULT PLANE.

allel with the bedding planes of the strata, one stratum having slid upon the other, and again some are horizontal or lateral faults, as if caused by horizontal tangential pressure.

In his monograph on this section, Mr. J. E. Spurr gives some general suggestions on the measurement of faults. "Faults are displacements along fractures. When rocks are subjected to great strain fractures take place, and the different parts of the rock tend to move past one another along their fractured planes. One part of the fractured rock mass may move upon the other in any direction, up, down, sidewise, or obliquely according to different conditions. When there

FIG. 76.—TREE SPLIT BY LANDSLIDE, SAN JUAN REGION, COLO.

is any pre-existing plane of weakness of the rock which is subjected to strain, the movement may take place along this plane. In sedimentary beds, movements along their bedding planes are common, and hence it is that the bedding planes as well as the laminæ of the rock are often found polished or slickensided in highly tilted sedimentary strata. The amount of movements in faults can be completely ascertained only by aid of independent and accidental phenomena. The existence of a movement may be determined by marks left on the slippery smooth surface, such as ground up rock, or "fault breccia," polished striated rock surfaces, and so on.

The amount of friction as displayed by the grinding up or polishing of the rock may not be proportional to the amount of movement, since faults with slight displacement are often accompanied by zones showing profound trituration, while others of far greater movement show to a much less degree the effects of friction. The friction depends upon the angle of chief stress to the sliding plane rather than the amount of movement along this plane. In rocks made up of various materials and of various consistency the amount of movement of a fault can ordinarily be estimated with more or less accuracy, the degree of closeness depending on the nature

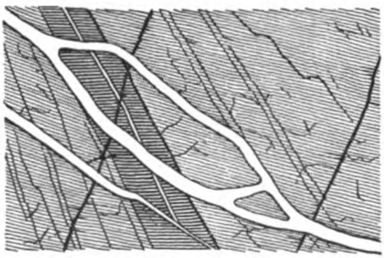


FIG. 77.—"HORSE" IN VEIN.

of differences in the composition of the rock masses. The commonest variations in rock masses constant enough for reliable data are in sedimentary beds, hence a general measurement of a fault movement is the separation of the two parts of an originally continuous stratum.

In mining geology we may regard sedimentary beds as only phenomena accidentally associated with faulting. Any fault in which the direction of movement is parallel with the plane of sedimentation will not cause any apparent displacement in a sedimentary bed whatever be the attitude of the fault plane in relation to the plane of the stratum. This may be true of faults in all sorts of positions, since the sedimentary beds may be so folded as to stand in any kind of position with reference to any fixed plane, such as the earth's surface. When the direction of movement in a fault lies at a slight angle to the plane of sedimentation, the apparent displacement of a stratum resulting from this fault will be only a slight

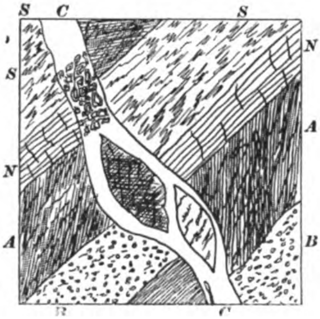


FIG. 78.—HORSES IN VEIN IN FAULT.

part of the actual fault movement, and it is only when the direction of movement is perpendicular to the plane of sedimentation that the separation of the parts of the faulted stratum is an accurate measurement of the movement. The most valuable criterion for measuring faults, besides sedimentary beds, are igneous bodies, such as dikes and bodies of ore; striæ or groovings on fault planes, showing direction of movement; and the composition of the fault breccia, showing in some degree the amount of movement. By taking several of these signs together we may often ascertain the amount and direction of the movement of a fault. This may sometimes be found out immediately, but generally it must be indirectly calculated.

The four terms generally employed with regard to fault movements are displacement, throw, heave and offset.

Displacement and throw refer to the separation of beds by a fault as seen in a vertical section. Each of these terms is used by some to indicate the distance along the fault plane between the broken ends of the bed, and sometimes the perpendicular distance measured on a horizontal plane between portions projected if necessary.

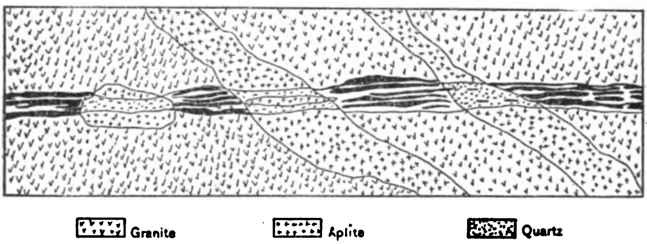


FIG. 79.—VEIN PASSING THROUGH DIFFERENT VARIETIES OF GRANITE.

Heave and offset are also used interchangeably, signifying the perpendicular distance measured on a horizontal plane between portions, projected if necessary, of a bed separated by a fault. Mr. Spurr suggests six terms to designate different parts of a fault movement.

For general outline work the terms "throw" and "vertical separation," referring to the measurements of a fault at its intersection with a vertical plane, and the term "heave" or "offset," indicating a measurement of a fault at its intersection with a horizontal plane are adopted. The throw and offset are parts of the actual fault movement, but of unknown value, while the vertical displacement sustains a certain relationship to the throw. When complete data are obtainable the terms total displacement, lateral separation and perpendicular separation are adopted. The perpendicular separation sustains a certain relationship to the lateral separation, as the latter does to the total displacement.

In the Aspen region the relation of folding to faulting is very conspicuous, the extreme and overthrust folding resulting in reverse faults, ordinary or more gentle folding in normal step faults. Some of the fault movements have been exceedingly recent, occurring after the glacial deposits, and from indications in the Della S. and other mines, such as crushing of timbers and distortion of mine workings, the movement seems still continuing. (Fig. 75.)

At Telluride and Rico are evidences of prodigious landslides accompanied by recent faulting. These slides are along or parallel with the more ancient lines of faulting in that region. Mr. W. Cross attributes these land slides and recent faults to earthquake action probably of volcanic origin.

CHAPTER V.

INFLUENCE OF COUNTRY ROCK ON VEINS.

The enclosing rock may influence or affect both the vein structure and the vein filling. A vein varies in width, uniformity, presence of splits and "horses" in passing from one rock to another. (Fig. 79.) It may pinch out in a tough rock, expand in an easily shattered material, become dissipated into a "stockwork" in brittle rock, or lost entirely in shales. In soluble rocks, like limestones and dolomites, the original fissure may be modified by solution and a cavernous-like structure, formed with replacement of the limestone by ore.

The vein, solid and continuous in one rock, may, in another, split up and form "horses" (Fig. 77), or become a zone of little stringers too poor to work. In the Guadalupe Mine, Chihuahua (Fig. 61), cited by Weed, a vein ten to forty feet wide, of profitable ore, changes in this manner eastward into small unworkable veinlets.

In schists the original fissure may have been due to a very slight movement along the plane of schistosity, resulting in "linked veins," composed of numerous connected lenses, as in the schistose region of the Carolinas. If the movement is distributed over several folia, the veins consist of a series of lenticular masses, overlapping one another, in a zone which may be over a hundred feet wide. As different rocks break in different ways, the character of the fissures formed in them will depend on the country. At Butte, Montana, the veins occur in a coarse grained granite with intrusions of aplite granite and dikes of porphyry. When these veins cross the porphyry, or aplite, they are narrowed. (Fig. 80.) At Neihart, Montana, a vein passing from schists into quartzite changes to many small fissures. Again, veins small and tight in granite widen out in rhyolite. At Cripple Creek, in hard andesite, the veins occupy clear-cut fissures, but in the soft rocks, a zone of small cracks.

In slates, if the fissure crosses the laminæ it is usually strong and well defined, but if following the lamination it is likely to be in lenses. At Cœur d'Alene, Idaho, the veins cross slates and quartzites with very little change. In Montana the rhyolites are unfavorable for well-defined

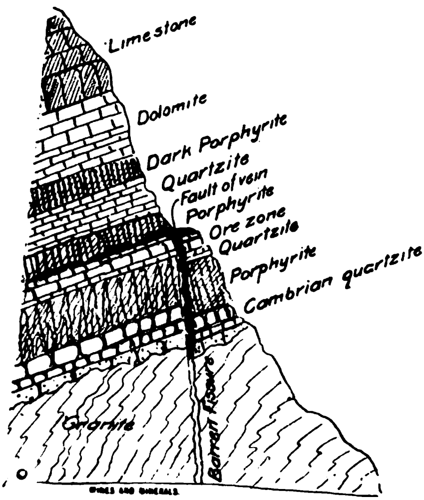


FIG. 80.—EXAMPLE OF ORE BODY IN FAULT PLANE, MOSQUITO CANON, AND CHANGE FROM BARRENNESS IN GRANITE TO RICH ORE IN PORPHYRY AND QUARTZITE.

constant veins, the rock being too easily shattered. The more basic granular rough rocks carrying augite and hornblende are more favorable for well-defined fissures. Each district has its peculiarities.

Where a vein passing through two different rocks shows one class of mineral in one rock and a different class in the other, the change is due to the influence of the wall rock. The nature of the wall rock is an important factor in the chemical reactions of the process of replacement in veins.

At Butte, Montana, copper veins occur as replacements of the rock along fracture planes. The veins cut

FIG. 31.—COMPOSITE FISSURE VEIN, CROESUS MINE, IDAHO.

two varieties of granite and a quartz porphyry. In the Butte granite the veins are rich in copper. In the Bluebird granite they are wide but lean. The Butte granite owes its richness, according to Weed, to the basic character of the rock and its greater content of the easily replaceable iron silicates.

Veins may be rich in passing through a dike of porphyry and poor on entering the slates. When the dike diminishes in size the vein may decrease in width. At Rico, Colorado, there is a marked change in passing from limestone into sandstone. The veins are richest in the dark sedimentaries. The carbonaceous matter of the sedimentaries is supposed to have acted as a precipitant of the ore. At Neihart, Montana, veins are barren in the dark-colored gneiss, but hold ore in the white feldspathic gneiss. In amphibolite the vein is barren and narrow, and no workable bodies occur in the diorite. In quartzite the veins are rich near the surface, but do not improve with depth. In the San Juan and La Plata regions of Colorado fissure veins are strong and productive in the andesitic breccia and the diorite rocks, but on penetrating the underlying sedimentaries the values generally give out.

Pyrite is a powerful precipitating agent. In solutions carrying copper salts, its reducing action is especially marked. Pyrite from the Butte veins left for several weeks in the natural mine waters became coated with copper glance. If later reconcentration occurs, as in so-called secondary enrichment, bonanzas are formed by reaction of pyrites on later solutions.

"To sum up," says Mr. Weed:

1. The structural character of vein fissures, such as course, width, etc., vary with the nature of the country rock.

2. The mineral contents of veins formed wholly by the filling of open fissures are not affected by the nature of the vein walls.

3. The mineral contents of ore deposits formed by metasomatic replacement vary with the nature of the enclosing rock.

CHAPTER VI.

GENERAL FEATURES. MOUNTAIN UPLIFTS AND MINERAL BELTS.

"The topography of a region is the result mainly of its geology. The Rocky Mountains rise from the prairie in long north and south ranges, consisting of Archæan axes, with Paleozoic and Mesozoic strata forming their east and west flanks. Great bodies of igneous rocks attended the various upheavals, the chief of which began, as has been said, at the close of the Cretaceous. The Rocky Mountains shade out on the west into a lofty plateau, extending to central Utah, where it is cut by the Wasatch Range. The Uintah Mountains are an east and west chain on the northern portion of this plateau. The rocks in the north are chiefly Tertiary, with Mesozoic and Paleozoic in the mountains. To the south are found Cretaceous and Triassic strata, with igneous rocks of great extent. The principal upheaval of the Wasatch began at the close of the Carboniferous, and seems to be still in progress.

Between the Wasatch and the Sierra Nevada ranges is the Great Basin region of lake bottoms of Quaternary age. The surface is diversified by north and south ranges of eruptive rock and tilted Paleozoic blocks. The depression of the Great Basin is succeeded by the lofty Sierras. The flanks of these mountains are largely metamorphosed Jurassic and Cretaceous rocks, with great igneous outflows. The surface of the great valley of California rises again in the Coast ranges, which slope to the Pacific Ocean. The principal upheaval of the Sierra Nevada began at the close of the Jurassic; that of the Coast range at the close of the Miocene Tertiary.

Oregon and Washington, along the coast, are formed of Cretaceous and Tertiary strata, but inland are vast outpourings of igneous rock, covering great portions of both states, as well as Idaho. The Carboniferous is extensive in the north, and runs eastward into Montana. Great Tertiary and Quaternary lakes abound.

The outlying Black Hills of South Dakota consist of a dome with an elliptical core and concentric Paleozoic and Mesozoic strata laid up around it. The Yellowstone Park consists chiefly of igneous volcanic rock in enormous development.

To the south the Rocky Mountain system, as it enters New Mexico, Texas and Old Mexico, breaks up into a number of minor ranges, surrounded by both Mesozoic and Paleozoic rocks, accompanied by great outflows of igneous rock, both in the mountains and on the prairie foothill region."*

In the great Cordillera system there seems to be a definite relation between mineral belts and well known lines and times of uplift. In this great mountain system are several well defined and more or less parallel mineral belts. One is at the foot of the Wasatch Mountains, represented by the Utah mines lying along the foothills, with a definite relation to the main line of the crests of this range. In a similar relation to the Sierra Nevada stand the gold and copper belts of California; and the quicksilver and cinnabar belt of this state is parallel to

*Kemp's ore deposits.

the Coast Range. The Arizona mineral belt lies diagonally across the country in a northeast and southwest direction. The mining districts of Nevada are not so easily grouped. These four distinct mineral belts are connected with the four great mountain-building changes and uplifts. The last of these was after the Miocene Tertiary, resulting in the uplift of the Coast range. The distributing force was greatest north and south of San Francisco.

An upheaval at the close of the Cretaceous raised the whole west central portion of the continent now occupied by the complicated system of the Rocky Mountains. The Wasatch Range is the western edge of this uplift. The dislocation took place on an old fault, coincident with the present western foot of that range, and here, as stated, lie the mines of Utah. The Sierra Nevada and ranges of the Great Basin were uplifted at the close of the Jurassic, the line of most intense disturbance coincided with the Sierra, and the greatest dislocation occurred along its western foot in what is marked by the "gold belt." The Paleozoic strata of Eastern Nevada, Western Utah and a part of Arizona, extending over part of the Plateau and the Colorado river region, past Prescott and on to Tombstone, were raised above the surface of the ancient sea by what was the earliest disturbance in the far west. The main Arizona belt nearly coincides with the borders of this Paleozoic uplift.

In Nevada the uplift, at the close of the Carboniferous, was gentle and without much crumpling of the rocks. The ore deposits are for the most part along the edge of the uplift, and are rudiments of the belt which is better defined in Arizona.

The age of mountain uplifts is determined by the strata involved. Thus we know that the great uplift of the Rockies occurred at the close of the Cretaceous, because both the Cretaceous rocks and all those of previous ages are uptilted with the mountains, while those of the Tertiary are not so severely tilted.

Mountain uplifts are not the immediate cause of mineral belts, but rather of fissuring and faulting. The uplift of a great range is not along a single line of dislocation, but such movements are accompanied by a great number of parallel faults and sets of fissures, with stringers running off into the surrounding country. A large area is fractured by innumerable rents in various directions; many of these may afterwards be filled by veins, and constitute a mining district.

Thus, there is seen to be a close relation between mineral belts and the time and line of uplift. The great Post-Cretaceous uplift of the Rockies determined some of the lines of our ore belts, and we find the line and time of uplift of some of the minor ranges of Colorado more or less coincident with the mineral belts found in them.

AGE OF MINERAL DEPOSITS.

Metals occur in Colorado in rocks of every geological age, but principally in the older rocks in the mountainous districts, and especially at the junction of igneous eruptive rocks with the sedimentaries. At what particular period the different mineral deposits were formed can not be positively or definitely stated. The gold deposits of Gilpin, Boulder and Clear Creek counties may have been during or after the Archæan, since they occur in granitic rocks; but as in the immediate vicinity there are no later rocks to limit the exact age of these deposits, they may have been much later, possibly as late even as the Cretaceous, when the great dynamic uplift of the mountain range took place. The silver-lead deposits of Leadville were certainly formed after the Carboniferous and before the mountain upheaval, because, in the first place, they penetrate Carboniferous rocks, and, in the second place, the fissures and faults, formed presumably at the time of the Cretaceous uplift, cut through and fault these deposits and are themselves generally barren of ore. The ore deposits of the Gunnison Region are later than the Cretaceous, because they occur in fissure veins cutting through the Cretaceous strata, and even through the Laramie coal beds. The Custer, San Juan and Cripple Creek deposits were probably formed in the Tertiary period, as they traverse andesites and other lavas presumably of that age of eruption. The iron ore deposits belong to the Cretaceous period, and the gold placers to the Quaternary. In general the Archæn, Cambrian, Silurian and Carboniferous; that is, the older rocks are the great carriers of the ores of precious metals. The sedimentaries of the foothills and plains are not found productive, yet in the heart of the mountains, where foldings, crumplings and volcanic eruptions have occurred, we find these same rocks prolific in minerals, notably in the Gunnison, Aspen, South Park and Leadville districts.

Ore deposits favor some particular geological horizon, not because that particular geological age was one especially productive of mineral at the time, but rather that the rocks of that age, by peculiar physical characteristics, happened to be better adapted for receiving mineral solutions, than the rocks of some other ages. Thus the "Blue Limestone" of the Lower Carboniferous throughout the Rocky Mountains has been particularly productive, not because it belonged to that age, but rather because the limestone itself being favorable for rceiving mineral deposits has been locally penetrated by eruptive rocks. Where the eruptive rocks do not occur the Carboniferous limestone is commonly as barren of mineral as other limestones generally are in Colorado.

ORE IN ROCKS OF ALL GEOLOGICAL PERIODS.

In the early days of metal mining, ore bodies were generally supposed to be restricted to fissure veins in granitic rocks of the Archæan age, then lead-silver deposits were found in rocks of Paleozoic age, such as those in the Lower Carboniferous limestone at Leadville and Aspen, Colorado. This was an upward advance in geological horizons, but mining geologists were slow to admit that ore bodies could occur higher in the series than in these Paleozoic rocks, because these being nearest the granite alone showed signs of general metamorphism; and metamorphic heat and alteration were justly considered essential to ore occurrence. Rocks above the Paleozoic series, as a rule, showed comparatively few signs of general metamorphic action. The power of intrusive sheets of porphyry to induce results similar to those observed in the great metamorphic series and to give rise to veins or ore deposits in any kind of rock at any period with which they came in contact, was for a while not generally recognized. The gradual discovery and recognition of ore bodies in one geological horizon after another, when associated with eruptive rocks, has so widened our knowledge of ore occurrences, that we are now able to state that ores may and do occur in the rocks of all the geological periods from the Archæan to the top of the Tertiary. Of this there is abundant proof in the West, and even in Colorado alone.

It is clearly shown that it is not the geological period that determines when and where ore deposition in mineral veins may occur, but rather certain concomitant circumstances, irrespective of geological eras, or even of kinds of rock. These circumstances or conditions appear to be great dynamic movements, such as upheaval, crumpling and folding of strata, accompanied by fissuring, metamorphic or volcanic heat, and igneous intrusions. As an example we may cite the Blue Limestone of thè Lower Carboniferous period, which is locally such a notable ore carrier at Leadville and Aspen. This rock is by no means confined to Leadville and Aspen, but has a wide extent in the Colorado mountains. In itself it is not ore producing, it cannot generate ore, nor have we any reason to believe that the period to which it belongs was remarkably characterized by ore bearing solutions. It is only a convenient ore recipient, and not found to carry ore (in these mountains) unless it is penetrated by intrusive bodies of eruptive porphyry. For example, in the beautiful Cañon of the Grand River, between Dotsero and Glenwood Springs, we pass through a gorge for some twenty miles or more, whose walls are formed of Paleozoic strata, including this "Blue Limestone" resting on granite, but throughout this cañon we look for evidences of ore bodies, mines, or prospect holes, but fail to see any until we reach Aspen, when these suddenly appear in abundance. This is due to the absence of porphyry intrusions in the one case and their presence in unusual quantities in the other. In the latter case also there is evidence of great uptilting, folding and faulting of the strata and general dynamic movements.

Take another instance, the Mesozoic rocks of the plains and the foot hills, including the Jura-Trias and the Cretaceous shales, sandstones and limestones are there devoid of ore bodies; but in the Gunnison Region around Crested Butte, Ruby, Irwin and Treasury Mountain, where these same rocks are highly metamorphosed and intensely penetrated by igneous porphyries, there is an abundance of ore.

Reviewing the ore occurrences in proof of the statement that ore bodies may and do occur in rocks of all geological periods, provided certain conditions are present, the Archæan ore bodies in the granitic and gneissic rocks are illustrated by the fissure veins in Boulder, Gilpin and Clear Creek Counties. These are usually at contact with, or in the neighborhood of, eruptions of porphyry, for even the granite is not by itself notable as an ore producer, unless there are porphyry intrusions somewhere in the mass. (Fig. 82.)

FIG. 82.—VOLCANIC CONGLOMERATE ON ERODED ALGONKIAN QUARTZITES, SAN JUAN, COLO.

Schists and quartzites of the Algonkian period lying next in geological order on the granite, are developed locally here and there throughout the mountains, as in South Boulder and Coal Creek cañons in the Front

Range, others near Salida in the Arkansas Valley, and a large body between Ironton and Ouray, in the San Juan. A vast area of schists and quartzites, also probably of Algonkian age, occurs in the Gunnison Region, near Iris and along the Tomichi. In nearly all these localities are signs of ore, and in some cases, as in the Gunnison, strong ore bearing veins accompanied by dikes of igneous rock.

Unconformably on the Algonkian are the Cambrian quartzites, the lowest in order of the Paleozoic sedimentary series. These are locally gold bearing, as in the Ground Hog mine and other mines at Red Cliff, and in Buckskin Cañon, South Park. Silurian limestone above this carries silver-lead ores in several mines in Park County, in the Mosquito Range.

The Lower Carboniferous is represented by the ore deposits of Leadville and Aspen associated with intrusive porphyry, and at Leadville ore zones are found in all the formations from the Weber Grits to the Cambrian resting on the granite beneath.

The Weber Grit series of the Middle and Upper Carboniferous is represented by the mines of Robinson and Kokomo. The strata there are intensely penetrated by intrusive porphyry sheets and dikes.

Numerous copper impregnations occur in the Jura-Trias rocks notably in the La Sal Mountains on the border line between Colorado and Utah, where deposits of uranium also occur. The Silver Reef of Utah is also in this period.

The "gold belt" of Ouray, as at the American Nettie mine, is in cavernous deposits in the metamorphosed sandstones of the Dakota Cretaceous period, accompanied by the intrusion of igneous dikes and sheets.

The Colorado Cretaceous is penetrated by galena veins in the Gunnison Region near Schofield.

Shales of the Montana-Cretaceous, altered into slates on Treasury Mountain in the Gunnison Region near Crested Butte, are traversed by numerous lead-silver veins, associated with dikes and intrusive porphyry sheets and laccolites.

Coal-bearing strata of the Laramie Cretaceous have fissure veins in them near Irwin and Ruby, with, *it is said,* coal on one wall, a porphyry dike on the other, and a contact silver vein between.

The Tertiary period in Colorado is represented by ore occurrences in eruptives poured out at the time, as at Cripple Creek, Silver Cliff and the San Juan region.

Lastly the Quaternary period is mineralized by the gold placers in which gold may occur from "grass roots" down to bedrock.

Thus in Colorado alone, every known geological period is represented by some kind of ore occurrence, and we might still further illustrate this if we included other regions in the great West.

It must be remembered that a rock in which a vein is found does not necessarily correspond with the geological age in which that fissure was opened and vein formed. For example, our fissure veins in the Archæan granite were not necessarily formed in the Archæan age, but may be as recent as the end of the Cretaceous. Similarly with other rocks; the ore deposits of Leadville, although occurring in Carboniferous limestones, are not of Carboniferous age, but more probably of much later date. A vein is necessarily of later date than the rock in which it is found.

Let not the miner or prospector conclude from this that ores are to be found "most anywhere," and "that gold is where you find it," and that you are as likely to find a fissure vein in digging a post hole out in the prairie as anywhere else.

There is the all important proviso that ores may occur in any kind of rock, of any or all geological periods, if certain concomitant conditions are present. These are principally: dynamic disturbance, metamorphic or igneous heat and the presence of eruptive rocks.

CHAPTER VII.

MODE OF OCCURRENCE OF MINERAL DEPOSITS.

Beds. "Ore beds are metalliferous deposits interstratified between sedimentary rocks of all geological ages." "They lie parallel to the planes of stratification, and follow all the contortions of the enclosing strata, hence they are thrown into folds, troughs, arches, saddles or basins. The upper portions of the arches may often have been removed by erosion, or the strata may be faulted." "The characteristic feature of a bed is that it is a member of a series of stratified rocks, and as such was laid down or formed after the rocks on which it rests and before those which lie on its top. This peculiarity at once distinguishes a bed from a true vein." Often there are no sharp limits between an ore bed and the enclosing rocks. The ore appears to impregnate the surrounding rock by a chemical interchange between the elements of the rock and the ore. Such a "metasomatic" interchange appears to have taken place in the silver-lead deposits of Leadville and Aspen between the ore and the limestones. According to Phillips, "A true ore bed never produces a 'combed' or 'ribbon' structure made up of symmetrical layers such as is common in so called 'true fissure veins,' and it is usually without the crystalline texture observable in veinstones."

Roof and Floor. "The layer above the ore bed is called the 'roof' of the deposit and the one below it the 'floor,' when it remains horizontal or nearly so, but when highly inclined the terms 'hanging wall' and 'foot wall' applied to true veins, are equally applicable to beds, but less expressive."

Thickness. The thickness of ore beds varies much and the bed may gradually thin out and disappear, but may also persist enough for all mining purposes.

Dip. The inclination of the floor from the plane of the horizon is its dip. It may be expressed in percentage or in degrees. If the floor is parallel with the horizon there is no dip, but horizontal beds are of rare occurrence because the disturbance causing tilting, bending and folding since the formation of the beds has been almost universal. The dip of beds may vary from almost zero to verticality, and may be observed in mine workings, or where a bed has been exposed on the side of a cañon.

Strike. The horizontal direction of a bed at right angles to its dip is its course or "strike". This will correspond with the bottom of a tunnel without grade following the deposit.

Country Rock. The rock enclosing beds or veins is called "country rock." The portions in direct contact with a vein are called the "hanging wall," and the "foot wall." Of course a vertical fissure vein can have neither roof nor floor, but only two walls.

Veins. According to Von Cotta, a vein is the filling of a fissure. Phillips divides veins into two classes, regular and irregular veins. "Regular unstratified deposits include true veins, segregated veins and gash veins. Irregular deposits include impregnations, fahlbands, contact and chamber deposits." Mineral veins are changeable in character, and of a complicated nature. There is a gradual passage from one form to another, so that classification is difficult. Nature abhors straight lines and sharp distinctions, and delights in blending one form imperceptibly with another. Veins are usually filled fissures formed in country rocks after those rocks had more or less consolidated. The popular term, "true fissure vein," for an ore deposit is vague and unscientific, for ores may occur in a variety of circumstances other than so-called true fissures, such as in shearage zones, in zones of multiple fracture, in decomposed dikes, in impregnated schists, at the intersection of faults or at contact between eruptive and other rocks. All veins do not carry metals; some are merely barren quartz, feldspar or calcspar. Veins may divide, split up or thin out, and are irregular in shape and structure, owing to the character of the fissures or other causes.

Dikes. Fissures filled with eruptive rocks such as the porphyries, diorites, etc., are called "dikes," or, if more or less horizontal, "intrusive sheets."

Lode. Lode is a more general term than vein or dike. It may designate simply a filled fissure or a zone of closely spaced fissuring, with possibly more or less impregnated or replaced country rock. As used in the acts of Congress, it is applicable to any zone or belt of mineralized rock, lying within boundaries clearly separating it from the neighboring rocks. It therefore covers all true veins as well as bedded deposits.

Dip and Strike. As in beds, the inclination of a vein from the plane of the horizon is its dip and the horizontal direction of the vein at right angles to its dip is its course or "strike." Both dip and strike of a vein often vary much, the former with depth, the latter with extension across the country. A vein will not infrequently begin

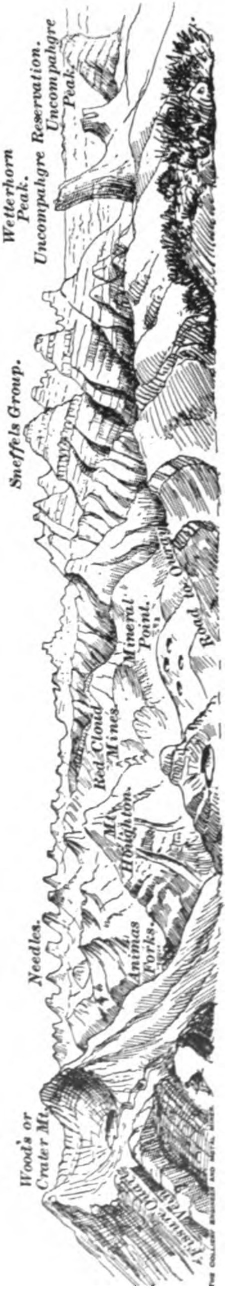


FIG. 83.—THE VOLCANIC MOUNTAINS OF THE SAN JUAN REGION, SHOWING PATHWAY OF FISSURE VEINS.

with a gentle dip, and steepen rapidly with depth. The ore deposits in Aspen Mountain commonly begin with a dip of 25° and at a depth of less than a thousand feet reach 60° or more. On a hill slope a vein may begin with a reversed dip, owing to the downward pressure of the hill side, and with depth into the hill dip in a contrary direction, and with increased depth gradually straighten up. The angle of dip is taken from the horizontal, not from the perpendicular. Thus a dip of 75° means one that is very steep, while a dip of only 10° is a gentle inclination. In Colorado nearly all our ore deposits, even the bedded class, dip more or less steeply, from 25° to 75°.

Outcrop. The outcrop of an ore deposit is that which appears at the surface. Sometimes it may be, as in the San Juan district, a vein of hard, white or rusty quartz, standing up in relief, by its (Fig. 83) superior hardness, like a low wall, above the surrounding country. Or again, in the same district, being composed of softer or more soluble substances than the prevailing lava sheets, it causes a depression or trough in the side of a hill, forming the pathway for a rivulet and marked by luxuriant vegetation. When this depression crosses the summit or profile of a mountain it leaves a well defined notch in the outline. By carefully looking for such notches a prospector may often detect or trace the passage of a vein. Commonly the outcrop consists of a decomposed mass of rock stained with oxide of iron, green or blue carbonate of copper, and sometimes, as at Cripple Creek, with purple fluorite. Such stains may occur without accompanying ore. This stained decomposed rock is called by the miners *"gossan"* or *"blossom."* In this "blossom" free gold is not unfrequently found, but unaltered sulphides, such as galena or iron pyrites are rarely met with on the outcrop. In the San Juan district, on Mineral Point, however, we have found galena at the grass roots, and broken off large chunks of it from a quartz vein outcropping on the surface. The same occurs at the Wilcox mine at Ymir, British Columbia, and in other places. An oxidized condition is desirable in gold bearing veins, for so far as it continues the gold is free, and the ore free milling, easily and economically treated

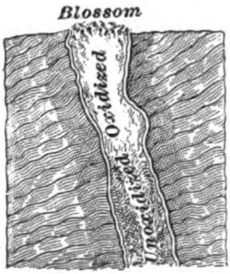


FIG. 84.—ILLUSTRATING OXIDIZED AND UNOXIDIZED PORTIONS OF FISSURE VEIN.

and often exceedingly rich. When the hard white quartz and the unoxidized pyrites of the vein are reached the ore may no longer be free milling, but must be smelted, or treated by some other more expensive process. Cases are said to occur where the pyrite itself is free milling, the gold being held mechanically in the pyrites, and the gold may sometimes even be found free in hard quartz, as in some of the mines on the "Mother lode" of California.

WIDTH OF VEINS.

Veins are in width or thickness from half an inch to a hundred feet or more. The widest "mother" veins are not always the most productive, though they are persistent in length and depth. The mammoth quartz veins of the San Juan district, often a hundred feet wide and traceable for miles over the surface of the country and down the sides of the deep cañons, are not the best for development. The ore in them is not sufficiently concentrated for profitable working. The limiting depth of these veins has never been reached by mining, and probably never will be. The vertical depth of a fissure vein may be in proportion to its width and ~~lateral~~ longitudinal extension along the surface.

FISSURE VEINS.

A fissure is a more or less extensive fracture in the rocks, caused by movements of the earth's crust in the process of mountain building, by earthquake and volcanic agencies, or by contraction of molten rocks and consolidating of the sedimentaries. Fissure veins are the filling of such fractures of indefinite length and depth with mineral matter other than eruptive rocks. They

FIG. 35.—FISSURE VEIN PARTLY CONFORMING TO STRATIFICATION PLANE, PARTLY DEVIATING FROM IT.

frequently occur in parallel systems and traverse the surrounding rocks independently of their structure or stratification. Fissure veins show signs of movement or slipping on the sides of the fissure, such as slickensides, gouge, crushed walls and breccia. The two walls do not generally coincide. The vein may in some part of its course follow the dip of the surrounding strata. Such a vein might appear to belong to the class of so-called *bedded* veins, but if with depth it should be found cutting across the strata it would be pronounced (Fig. 85) a *true fissure* vein. The appearance of slickensides or other signs of motion on the walls of the apparently bedded portions would prove it to be a true vein, and show that actual fissuring had occurred prior to the vein filling.

FIG. 86.—A WATERFALL FOLLOWING THE COURSE OF A FISSURE VEIN IN THE SAN JUAN REGION.

Such veins are common in uptilted schistose or slaty rocks, as at the Minnie-Moore mine in Idaho.

A fissure vein may surpass other forms of vein occurrence in persistency and comparative regularity to great depths. It must not be assumed, however, that it will continue equally rich or equally poor throughout its course. There may be comparatively barren and rich spots, pinches, widenings and local combinations of richer or poorer mineral, but as a rule the vein is not likely to give out entirely within mining depths.

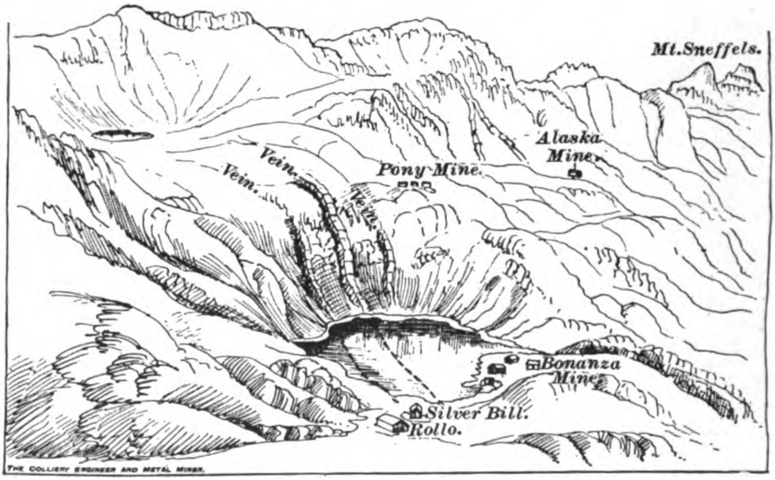


FIG. 87.—PARALLEL FISSURE VEINS, LAKE COMO, SAN JUAN.

Fissure veins frequently occur in nearly parallel groups, forming a mining district, and in that district certain peculiar veins may be grouped together as forming a *belt*. Thus the Boulder district of Colorado occupies a certain isolated area, outside of which few mineral deposits of commercial importance occur for some distance. There are in that district several distinct belts carrying characteristic ores, such as the telluride, the pyritiferous gold bearing, and the argentiferous galena belt. The Central City region of Gilpin is characterized by auriferous pyrites belts; the Georgetown district, not far distant, by argentiferous belts, and Idaho Springs, lying between the two, by both gold and silver belts.

In Colorado fissure veins are characteristic of the Archæan granitic series. In fact, all the veins in that series are fissure veins. Locally they occur, as in the San Juan region, cutting through eruptive rocks. Here mineral veins penetrate and traverse huge sheets of lava, whose united thickness is from two to five thousand feet. The veins of the San Juan consist of a hard, gray, jaspery, "horn" quartz, and produce lead, bismuthinite, gray copper, gold and silver bearing ores. At Creede silver deposits occur in fissure veins in andesite and rhyolite lavas. In the Gunnison and Elk Mountain regions fissures traverse all the formations from the Archæan granite to the top of the Cretaceous coal beds. The Carboniferous limestones of Rico, Colorado, are also traversed by ore-bearing fissures. Outside of these formations few fissure veins occur. Nearly all other mineral deposits, such as those in limestone regions, come under the head of bedded veins, blanket veins, pipe veins or pockets.

Ore Deposits commonly occur at the junction or contact of two dissimilar rocks, as between quartzite and limestone, or limestone and dolomite, or more commonly between porphyry and some other rock. The contact ore deposits of Leadville are at the contact of porphyry, dolomite-blue-limestone and quartzites. The mineral may also occur between the stratification planes of the same class of rock, sandwiched in between two layers of limestone, and sometimes impregnating the layers on either side for some distance from the dividing line of the two strata, which is commonly the line of principal concentration of ore, and frequently descends from this concentration line through cross joints to form large pockets in the limestone.

When occupying a true fissure, that is, one cutting across the stratification or bedding planes, ore bodies may locally or for a short distance impregnate the adjacent walls of country rock more or less, and even granite and gneiss walls are often thus impregnated to a small extent.

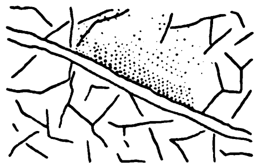


FIG. 88.—IMPREGNATION OF ROCK BY VEIN.

Mineralized Dikes. Mineral may be found in the heart of a dike, or the whole dike may be so impregnated as to constitute in a sense a vein. This is often the case in our pyritiferous and telluride gold deposits. Near the surface and often for considerable depth the rock is decomposed and the pyrites oxidized, liberating the gold which is entangled in the "gossan" in wires, flakes or small nuggets. Such gold-bearing dikes are found at Breckenridge and South Park, Colorado, also in Idaho, Old Mexico and many other gold mining regions.

The Printer Boy gold mine of Leadville is a vertical deposit or fracture plane in a dike of quartz porphyry, rusty and much decomposed near the surface. At Cripple Creek gold ores in pyrite and telluride minerals impregnate dikes of phonolite and nepheline basalt. At the Lion mine near Prescott, Arizona, a green dike of eruptive diorite penetrates the granite. The dike is traversed by numerous veinlets of white quartz, which near the decomposed and rusty surface are rich in free gold. At a slight depth the quartz veins become charged with unoxidized iron pyrites sufficiently rich in gold to merit treatment by smelting.

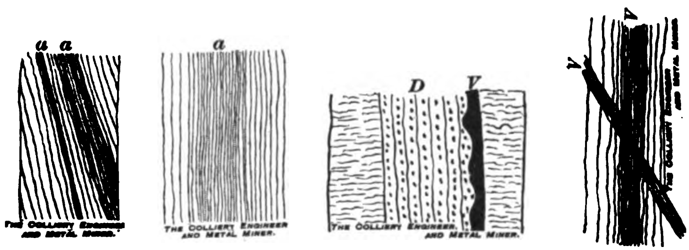


FIG. 89.—VEINS TYPICAL OF THE CRIPPLE CREEK REGION.

Veinstone or Gangue. In most ore deposits, whether they be called fissure veins, true veins, gash veins, blanket veins or by whatever name they may be designated, the space between the confining walls is occupied by gangue or veinstone, consisting usually of some of the elements of the adjacent country rock in an altered condition. The commonest of these veinstones is quartz which is of either coarse or fine crystalline structure. In the San Juan region it is commonly of a very fine grained, hard, jaspery variety, of a blue gray color, and known as "horn quartz." In other localities the quartz is coarsely crystalline, like loaf sugar, frequently containing beautiful little cavities called "vughs," "geodes," or "druses," lined with long, perfect crystals. In the telluride mining districts, as at Boulder, there is a peculiar, fine grained, dark gray, horn quartz which is so characteristic of telluride deposits as to be locally called "telluride quartz."

Calcspar in white or yellowish crystalline condition is sometimes a veinstone, particularly in limestone districts. Crystalline dolomite also appears in the dolomite limestones, and stalactites of aragonite are characteristic of the cavernous openings found associated with lead ores in limestones.

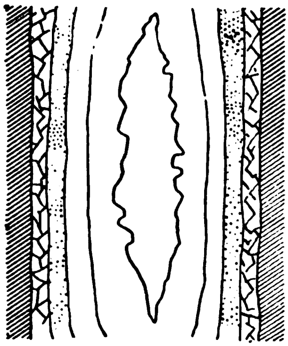


FIG. 90.—GEODE IN FISSURE VEIN.

In the Silver-Islet mine, Pitkin County, Colorado, in the Sacramento mine, South Park, and in several of the Leadville and Aspen mines such caverns lined with stalactites occur. These caverns were evidently formed after the deposition of the ore bodies, since they are hollowed out of limestone and ore bodies alike, by surface waters which by the assistance of carbonic acid have enlarged the jointage cracks and eventually formed caverns either in these cracks or in the lines between the planes of stratification.

Rhodocrosite, a beautiful rose-colored carbonate of manganese, also rhodonite, a pink silicate of manangese, are found in the gangue of some of the mines of the San Juan and South Park regions.

Fluor spar, a soft mineral sometimes of a pale green, more often of a purple color, occurs in fissure veins in the granite and igneous rocks.

Purple fluorite and the purple stains of fluorite are a frequent accompaniment of the telluride gold bearing ores of Cripple Creek.

Barite, or heavy spar, occurs as a veinstone associated sometimes with lime-crystals in limestone districts. It is not confined to limestone regions, for it is found forming the gangue in several mines in the eruptive

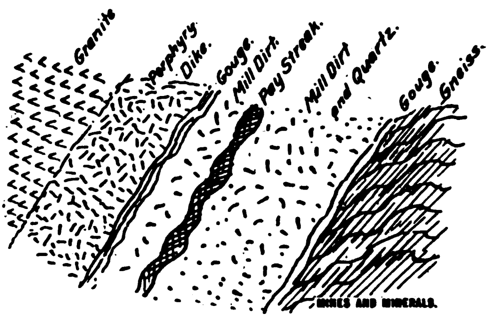


FIG. 91.—IDEAL SECTION OF A FISSURE VEIN.

rocks of San Juan, notably at the Bonanza mine on the shore of Lake Como, where it is associated with considerable gray copper. In Hall's Valley it occurs in a vein in gneiss also associated with rich deposits of gray copper. Though resembling calcspar in appearance it can readily be distinguished by its great specific gravity; as it usually occurs massive, its different crystallization is not always to be seen. Its luster is more pearly than that of ordinary calcite. It does not effervesce with acids, and under the blowpipe emits a green flame and decrepitates. White veins of calcspar, common enough throughout the limestone rocks, may or may not point to the presence of ore, but barite is often an indication of a mineral lead. It is a significant fact showing the relation of ore deposits to porphyry that barite is detected as an element in the feldspars of certain porphyries. Barite is a refrac-

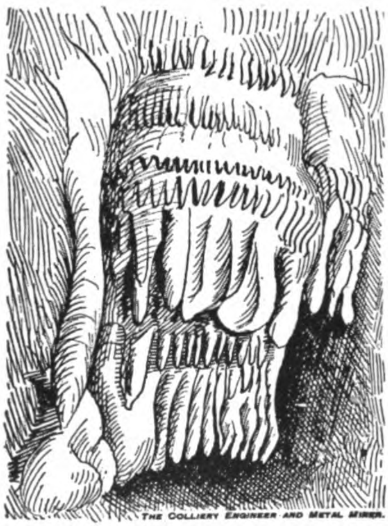


FIG. 92.—STALACTITES, SILVER ISLET MINE, PITKIN, COLO.

tory substance in smelting processes and troublesome if in excess.

With these veinstones is often a good deal of iron oxide, sometimes oxide of manganese, and carbonate of copper stains. Iron-carbonate in the form of spathic iron or siderite, very like orthoclase in appearance, only heavier.

occurs in the gangue of the Whale and Freeland mines at Idaho Springs, Colorado.

The gangue so far from being a foreign substance derived from unknown rocks, or from the bowels of the earth through ascending solutions, is generally derived from and its character determined by the surrounding "country" rock. Often it is little more than a slight alteration or decomposition of that country rock along a fissure or other line of weakness. Limestone yields calcite for veinstone, granite gives its elements of quartz or feldspar, or both combined in pegmatite. The porphyries yield a clay com-

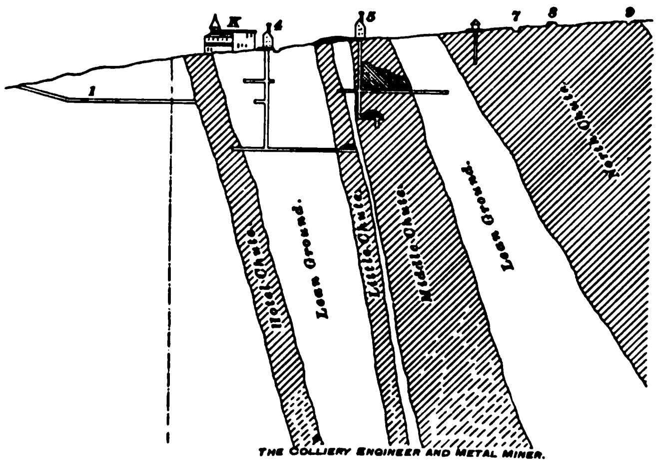


FIG. 93.—ORE CHUTES AT GOLD COIN, VICTOR, COLORADO.

posed of the elements of their feldspars and some quartz; and seem largely responsible for the barite.

Sometimes the gangue is a porphyry dike more or less decomposed or highly charged with pyrites lying between walls of granite or other country rock.

Ore in the Gangue. Through the gangue the precious metal is distributed in narrow patches or strings, or in large crystalline masses, or in isolated or scattered crystals, or in decomposed masses. When a vein is said to be "ten feet wide" that is the width of the gangue from wall to wall. The ore body may occupy but a few inches of that width or be thinly, sparingly and irregularly distributed in it, the remainder being quartz or some other veinstone. It is common to find one or more rather well-

FIG. 94.—HORSES IN VEINS IN ANIMAS CANON, SAN JUAN.

defined and continuous streaks or courses of ore having a tendency to keep one or the other wall, at times to cross from wall to wall. Again, instead of the ore being generally distributed in the vein, it may occur in *chutes* or *chimneys,* which may have a dip of their own, different in direction from that of the vein.

Gouge or Selvage. A layer or sheet of clay, called *gouge,* or *selvage,* often lines one or both walls of a vein between the country rock and the gangue or veinstone. It is derived from the elements of the adjacent country rock. It often contains some rich decomposed mineral, such as sulphides of silver. It sometimes occurs in the heart of a vein, especially if that vein has been reopened anew by movements of the strata. The "Chinese tallow" gouge of Leadville results from the decomposition of the feldspar in the adjacent white porphyry and is a hydrous-silicate of alumina. In the granite veins in Clear Creek County the gouge is derived from the feldspars of the granite.

Gouge is sometimes useful in defining the limit of the vein between walls, thus preventing unprofitable exploration into the "country." It is also a guide for following down a vein when mineral or gangue may be wanting or obscure.

SPLIT VEINS, SAN JUAN.

Breccias and Horses. Some veins enclose fragments of the country rock. When these are small and angular they are called "breccia" and the vein is said to be brecciated (Fig. 62, "Brecciated Vein"); when so large as to split the vein they are called "horses." (Fig. 94.) "Horses in Veins in Animas Canon, San Juan.") In the San Juan region of Colorado, where wonderful opportunities are presented for observing extensive sections of great fissure veins descending the faces of cliffs on either side of a cañon, for two or three thousand feet, such broad veins, at intervals split up into two or three arms enclosing large fragments, or "horses" of the lava country rock, and again unite to form the main vein. These veins occupy a once shattered fissure. The veinstone insinuated itself between the shattered portions, sometimes forming breccia, at others, "horses."

The rings of quartz or mineral sometimes surrounding the breccia are know as "cockade ores." (See Fig. 62.) At the Bassick mine, Rosita, Colorado, the breccia filling the throat of an old volcano is surrounded by

FIG. 95.—SPLIT VEINS, SAN JUAN.

some four or five concentric layers of the precious metals. The Bull Domingo mine, in the same region, exhibits shells of galena surrounding boulders of gneiss. The Forest Queen mine, in the Gunnison region, furnishes another example of a brecciated vein with cockade ores, in this case rich in silver sulphides.

BANDED, COMBED OR RIBBON STRUCTURE.

"The various minerals filling a vein fissure are frequently arranged in a succession of bands parallel to the walls. These bands or combs are aggregations of crystalline minerals, the separate crystals of which are usually arranged with their longer axes at right angles to the wall of the lode, while their crystalline form is more perfectly developed at the ends turned towards its center than at the other extremity." These combs meeting, if their crystals happen to be long pyramids of quartz, suggest rows of teeth clenching and interlocking. The vein filled fissure being a line of weakness, may be reopened by mountain movements, and other or different combinations of ore introduced. "The ribbon or banded structure indicates long continued chemical action, occasionally interrupted, but again renewed under different conditions, the substances deposited varying with the nature of the minerals held in solution at the time the bands were severally formed. Some parts of a vein may show this comb structure, while others show no trace of any particular arrangement." The arrangement of minerals in these alternate bands of ribbons could be produced only by solution or sublimation. The successive layers are produced by deposits parallel to the walls, while the crystals have their axes directed to the center of the vein.

Towards the center of large quartz veins, *vughs* or cavities of a lenticular shape sometimes occur, lined with beautiful quartz crystals, their points directed to the center of the cavity, at right angles to the wall. There seems to have been an open space here, or a relief of pressure sufficient to permit the quartz to crystallize out in large and perfect forms. This banded or combed and vugh structure is common in the San Juan district of Colorado and in Cornwall, England. In the basaltic rocks of Table Mountain, at Golden, Colo., cavities have been formed in the molten lava by steam bubbles. These cavities were subsequently lined by a succession of zeolite crystals. The minerals for these crystals were derived by solutions from the basalt in different degrees of combination, and so crystallized in different forms. This is probably analogous to the vein-ribbon structure.

METASOMATIC REPLACEMENT.

Quartz substitutes itself for other mineral elements or for portions of the country rock, as matter in a wounded member substitutes itself in the place of the natural flesh. Rocks have been wounded by many cracks. These cracks have been healed by silicious matter supplied from the adjacent rocks in solutions. The silicious matter not only heals the cracks, but eats into and replaces portions of the country rock on either side of the original fissure, with its own matter. This substitution or metasomatic replacement is not unlike that which takes place in the fossilization of a tree trunk, buried in mud, soaked with water carrying silica. As the cells of woody fibre gradually decay and pass away each particle of wood is replaced by a particle of silica, and the result is a tree replaced by silica or a silicified, fossilized trunk.

Breccias may sometimes be formed by quartz substituting itself for portions of the country rock, leaving harder or unchanged portions not yet substituted, remaining in the vein surrounded by the quartz.

Limestones by their tendency to solubility and chemical reactions offer favorable conditions for mineral solutions to deposit by metasomatic interchange.

J. F. Kemp in his Ore Deposits has adopted the following classification, which, briefly stated, is:

I. Deposits of igneous origin. Extremely basic developments of fused magma. Peridotite forming iron ore, as at Cumberland, R. I.; titaniferous magnetite, Jacupiranga, Brazil; iron ores in numerous gabbros; nickel-bearing pyrrhotite, chromite in serpentine, etc.

II. Deposited from solution. Surface precipitations forming beds due to:

1. Oxidation—bog iron ores.

2. Sulphurous exhalations from decaying organic matter—pyrite.

3. Reduction by carbonaceous, organic matter—pyrite and ferrous sulphate.

4. Evaporation, cooling, loss of pressure in hot springs deposits, as at Steamboat Springs, Nevada.

5. Secretions of living organisms—iron ores from algæ.

Disseminations in particular beds or sheets, due to:

1. Selective porosity, as silver ores in porous rhyolite, in sandstones, and copper in conglomerate.

2. Selective precipitation by calcareous matter, e. g., the telluride gold ores of the Black Hills, South Dakota.

Filling joints caused by cooling or drying; veins as in the Mississippi Valley.

Occupying chambers or caves, as at Cave mine, Utah.

Occupying collapsed brecciated beds, caused by solution and removal of support. Occupying cracks at bends of monoclines, anticlinal summits, synclinal troughs, often with replacement of walls.

Occupying shear-zones or dynamically crushed strips along faults, as at Butte, Montana.

True veins occupying extended fissures, often with lateral enlargements (vein chambers).

Occupying volcanic rocks, in agglomerates, as at the Bassick mine, near Rosita, Colorado.

Replacements in troughs, as the hematites of Lake Superior.

Contact deposits, where igneous rocks always form one wall.

Segregations formed in the alteration of igneous rocks (chromite in serpentine).

Deposited from suspension, as residual deposits. Metal bearing sands and gravels (beach-sand placers, ancient and recent).

Residual concentrates left by weathering of the matrix.

The above are practically all the recognized forms of ore deposits.

CHAPTER VIII.

PRINCIPAL ORES OF USEFUL METALS.

Metals occurring in a nearly pure state in nature are called *native*. While gold, silver and occasionally copper are found native in Colorado, these for the most part, as well as the rest of the useful metals, are derived from ores.

To the miner an *ore* means any material containing a workable proportion of a metal. Strictly speaking, an *ore* is a simple or complex chemical compound of a metal and a non-metallic element. The commonest non-metallic elements which unite with metals to form ores in simple compounds are sulphur, chlorine and oxygen; and in complex compounds, carbonic and sulphuric acids. Of the eight or nine hundred known mineral species, probably a considerable proportion might be called ores; only a few are of sufficient importance to warrant individual mention.

The following descriptions are for the most part from Dana; reference has also been made to Dr. J. Ohly's "Rare Metals."

GOLD.

Native gold in Colorado is sometimes visible to the naked eye in the form of little hairs or wires, or as minute grains, thin flakes, or fern-like crystals. Nuggets rarely occur in veins, but together with fine flakes are found in placers.

Gold is comparatively soft, the hardness being 2.5 to 3.1, it can be cut with a knife; is highly malleable and ductile. The specific gravity of free gold is between 19 and 20. The lustre is metallic and the color yellow. Native gold nearly always contains some silver, and its color and density vary with the amount of silver. When the values become equal the color of the alloy is white.

By far the larger part of the gold of the world is obtained from the native metal. Minerals containing gold are rare; besides auriferous pyrite, arsenopyrite and chalcopyrite, the most important are the tellurides.

TELLURIUM.

Tellurium is one of the rare elements. It was discovered by Mueller in 1782, in some specimens of gold ore, from Transylvania, and is chiefly interesting as being the only known element which combines with gold in nature. Colorado is very rich in gold tellurides. Boulder County and Teller County are famous for the production of these ores and they are contributing largely to the value of the output of other districts, such as the San Juan and the La Platas. They also occur in considerable quantities in the Black Hills of South Dakota, in Montana and California. The three most important tellurides of gold are sylvanite, calaverite and petzite.

Sylvanite. On account of the triangular and rhombic figures, not unlike Hebrew letters, which mark the distribution of this mineral, in the gangue, it is called *graphic tellurium.* It is a telluride of gold and silver, often associated with lead and antimony, its color is steel-gray to silver-white, sometimes brassy yellow. Hardness from 1.5 to 2. Gravity between 7.9 and 8.3. It is very sectile, fracture uneven, and melts easily before the blow-pipe, coloring the flame greenish-blue. Approximate composition of Colorado sylvanite is gold, 30; silver, 10; tellurium, 60.

Calaverite. This mineral was first found in Calaveras County, California. It occurs massive and is very brittle. The color is bronze-yellow; streak, yellowish-gray; fracture, uneven; subconchoidal. Approximate composition is gold, 39; silver, 3; tellurium, 58.

Petzite. Is an auriferous silver compound. It occurs in the Red Cloud mine of Colorado, and in several of the California mines. The fracture is conchoidal; color, steel-gray to iron-black; streak, iron-black. Hardness, 2.5, gravity from 9 to 9.4. Approximate composition is gold, 25; silver, 42; tellurium, 33.

PLATINUM.

Metallic platinum was found in the northwestern part of South America in 1735. It was called *white gold,* and received its name from platina, the diminutive form of the Spanish plata, meaning silver. It is found in paying quantities chiefly in alluvial deposits. Of the world's production for 1900, Russia furnished 90 per cent. A very useful metal, and as the demand is greater than the supply, the price is maintained as about equal to that of gold. When native it has a hardness of 4 to

4.5; specific gravity 16 to 19. When pure its gravity is 21.5; it is then of a tin white color, extremely ductile and malleable. It is infusible, and soluble only in heated nitro-muriatic acid. California platinum contains about 86 per cent. of the metal. Platinum is found in place in very basic eruptive rocks such as olivine rocks and peridotite, in Alaska. In the Urals it occurs in placers. The ore of the New Rambler mine of Wyoming is said to contain platinum and palladium, with 18 to 20 per cent. of copper to the ton. Usually associated with platinum are the rare metals, palladium, rhodium and others.

Iridosmine. Is a compound of iridium and osmium resembling platinum, but of a whiter color, found in gravel diggings in flattened scales.

SILVER.

When native, the color is a fine silver-white; but it easily tarnishes, and a little sulphur or sulphuretted hydrogen will turn the metal black. Its hardness is 2.5 to 3; specific gravity when pure, 10.6. It is highly malleable and ductile and is the best known conductor of electricity. It occurs sometimes in distinct crystals, more frequently as wire silver, in branching or arborescent forms, in plates and scales, and massive up to several hundred pounds in weight. It is dissolved by nitric acid, forming silver nitrate. Though native silver is rather abundant, the world's supply comes principally from the ores.

Argentite. Called also Vitreous Silver, or Silver Glance is a silver sulphide containing when pure 87 per cent. of metallic silver. Occurs in cubic, or octahedral crystals, often growing together, also filiform, more often amorphous. Hardness, 2; specific gravity, 7.3; luster, metallic; color and streak, grayish-black. It is cut with the knife almost like lead, and unlike nearly all other sulphides, which are brittle and go to pieces with a blow, flattens somewhat under the hammer. When heated on charcoal by the blow-pipe the sulphur is driven off and silver remains.

Pyrargyrite. This is a silver sulphide with antimony. It is known as *ruby silver.* The color is dark or purplish-red, often black; streak, cochineal-red. The hardness is 2 to 2.5, and specific gravity 5.8. Its composition is about 60 silver; 22 antimony, and 18 sulphur.

Proustite. Also called *ruby silver,* is a silver sulphide with arsenic. Hardness, 2.5; specific gravity, 5.6; color, bright red; streak, bright red. Fracture, conchoidal and uneven. The approximate composition is silver, 65; arsenic, 15; sulphur, 20.

Both pyrargyrite and proustite crystallize in hexagonal prisms and resemble each other closely in character. They are decomposed by nitric acid. Heated on charcoal the former gives off dense antimony fumes, the latter yields fumes of arsenic. If roasted with soda on charcoal both minerals give a silver globule.

Stephanite. Stephanite or black silver is silver sulphide with antimony. Hardness 2 to 2.5; specific gravity, 6.3; luster, metallic; color, streak and powder iron-black. The approximate composition is silver, 68.5; antimony, 15; sulphur, 16.5.

Cerargyrite. This ore, popularly called *horn silver,* is a chloride of silver, containing about 75.3% silver and 24.7% chlorine. Its luster is resinous; color, pearly-gray, grayish-green, whitish, violet and sometimes colorless. Translucent. Hardness, 1 to 1.5; specific gravity, 5.5. Perfectly sectile, cutting like a piece of wax. It is not dissolved by nitric acid. This is a rather rare but very valuable ore of silver.

Embolite. This is a bromide of silver and somewhat resembles horn silver; the hardness is 1 to 1.5; specific gravity, 5.5. Luster resinous and color green. Composition: silver, 67; chlorine, 13; bromine, 20.

Freieslebenite. Gray silver ore. Has a metallic luster. The color and streak are light steel-gray, also blackish lead-gray. It is easily cut by the knife, and is somewhat brittle. Hardness, 2 to 2.5; specific gravity, 6 to 6.4. The composition is silver, 22; lead, 30; antimony, 28; sulphur, 18; iron and copper, 2.

Polybasite. Hardness, 2 to 3; specific gravity, 6.2; luster, metallic; color, iron-black. When in thin crystals the color is cherry-red by transmitted light. Streak iron-black. Fracture, uneven. Occurs crystallized in short tabular prisms; also massive and disseminated. Composition: Sulphur, 14.8; antimony, 9.7; silver, 75.5. Sometimes contains copper and arsenic.

There are, besides these, a number of other ores carrying silver, but of slight commercial value.

MERCURY.

This remarkable metal is liquid at ordinary temperature, but becomes solid at 40 degrees F. The specific gravity is 13.6. Luster, brilliant metallic and color silver white. Native mercury is of rare occurrence in nature. It is, however, sometimes found in minute globules in the rocks. The common ore is cinnabar.

Cinnabar. Is the sulphide of mercury. The luster is adamantine and color bright cochineal-red to red-brown or rarely dull lead-gray. The streak is scarlet, and the scarlet powder is the valuable pigment called *vermilion.*

The hardness is 2 to 2.5; gravity, 8 to 9. If the cinnabar is not a pure mass, but distributed through a clayey gangue, the density of the whole may be considerably below 8. It occurs in masses, sometimes also in small rhombohedral or prismatic crystals. Its composition is mercury 86.2, sulphur 13.8. Cinnabar resembles some forms of red oxide of iron and chromate of lead. The difference is easily found before the heat of the blow-pipe by which the cinnabar is entirely volatilized, and if there is any residue, it is only the gangue.

The Almaden mine of Spain was worked as early as 415 B. C., and seems to be inexhaustible. There are mines at Idria, in Carniola; Kivei Chan, China; also in Peru, Texas and California. Away from the Pacific slope few deposits are know in North America.

COPPER.

Native copper is most commonly found in strings or wires, in grains, plates and masses. The hardness is 2.5 to 3; specific gravity, 8.8. Luster, metallic; color, copper-red. It is highly malleable and ductile, and is an excellent conductor of both heat and electricity. Nitric acid dissolves copper and many of its ores.

Chalcocite. This is a copper sulphide and is one of the most valuable of the copper ores. The hardness is 2.5 to 3; gravity about 5.6. Luster, when fresh, is brilliant metallic; color, bluish-black to black. It is brittle under the hammer, but can be cut with the knife. The composition is, copper, 79.8; sulphur, 20.2. On charcoal it is reduced by the blow-pipe to metallic copper.

Chalcopyrite. Copper pyrite is a sulphide of copper and iron. The composition is sulphur, 35; copper 34.5; iron, 30.5. Hardness, 3.5 to 4; the streak is greenish-black. Fracture conchoidal and uneven. It is often tarnished on the surface and the color deepened. Sometimes it is iridescent, so as to resemble bornite, from which it can be easily distinguished by breaking off a scale and showing the color on a fresh fracture. It can be distinguished from iron pyrites by its inferior hardness and by its color; while sometimes mistaken for gold, it is easily distingnished from that metal by being brittle, and being readily decomposed by nitric acid. It is a very common mineral and, usually in minute particles, is frequently found in quartz veins with pyrite, galena and gold. When occurring in large masses, as in the state of Montana, be cause of the high percentage of copper, it is a very valuable ore.

Bornite. Called also *Purple Copper, Variegated Copper, Horseflesh Copper, Peacock Copper* and *Erubescite,* is a sulphide of iron and copper. The hardness is 3, specific gravity, 4.5 to 5.5. Copper and iron are not always present in the same proportions. One analysis gives: sulphur 28.1, copper 55.5 and iron 16.4. The color of a fresh fracture is reddish bronze, which changes gradually and becomes variegated, showing the red, blue and purple peacock tints. The streak and powder are a pale, grayish black. It is brittle and easily scratched with the knife. Dissolves in nitric acid with separation of sulphur, giving a blue solution.

Tetrahedrite: or *Gray Copper.* Is a sulphide of antimony and copper. It is a complex ore and often carries iron, arsenic, zinc, silver and sometimes mercury.

Hardness, 3 to 4.5; specific gravity, 4.5 to 5.1. Luster, metallic, color from light gray to iron black. Streak and powder, gray to black; sometimes brown and cherry-red. It is rather brittle and has an uneven, sub-conchoidal fracture. Dissolved by nitric acid. Colorado has afforded some fine specimens of gray copper.

Cuprite. This is the red oxide of copper, and not only a beautiful mineral, but a valuable ore. Composition when pure, oxygen 11.2. copper 88.8. Hardness 3.5 to 4, specific gravity about 6. The luster is adamantine, on some surfaces, metallic to earthy. The color in the clear cystals is bright cochineal-red. Streak always brownish red. The fracture is subconchoidal and uneven. The crystals are often spun out into long threads, forming a matted mass of bright red hairs. Cuprite commonly occurs massive. It is dissolved by nitric acid. A fragment on charcoal is easily reduced to metallic copper.

Tenorite. Is the black oxide of copper. Composition: oxygen, 20.15; copper, 79.85. Usually occurs massive or as a dull, earthy powder. Hardness, 3; specific gravity, 6. Color, steel-gray to grayish black. Dissolved by nitric acid.

Malachite. This is the green carbonate of copper. Composition: Carbon dioxide, 19.9; cupric oxide, 71.9; water, 8.2. The hardness is 3.5 to 4; and specific gravity about 4. The color is bright green; the streak a little paler. It occurs rarely in acicular crystals. The common forms have a mammillary surface and a concentric fibrous structure. The malachite of Siberia is close and compact, and is cut and polished to form the well-known and highly ornamental malachite of commerce. Fine specimens have been found in Arizona. It dissolves in nitric acid with effervescence.

Azurite. The blue carbonate of copper is not so common as malachite. It is a beautiful mineral forming large transparent crystals of a deep blue color. The hardness is 3.5 to 4, and the gravity 3.8. Luster, vitreous. Color azure blue, streak somewhat lighter. It differs from malachite in containing less water. It contains about 61% copper, the remainder being carbonic acid, oxygen and water. The blue crystals are often changed within to a fibrous mass of malachite. The Copper Queen and other mines of Arizona have furnished fine specimens. Like all the foregoing copper ores, it is dissolved by nitric acid.

Dioptase. This is a silicate of copper of a beautiful, emerald color. It is a rare mineral known to occur only in a few localities, one of which is Arizona. It contains about 50% cupric oxide, the remainder is silica and water.

Chrysocolla. This is a bluish green or sky-blue silicate of copper. The hardness is 2 to 4; the specific gravity 2.2. It contains about 35% copper, the remainder being silica, oxygen, water and some iron oxide. It occurs in massive forms, looks a little like malachite, but is a paler green, of coarser texture, a smoother surface and a somewhat waxy luster. It is not an uncommon product of the alteration of other copper minerals.

Atacamite. Hardness, 3. to 3.5; specific gravity, 3.7 to 4.3. Luster, adamantine to vitreous. Color, bright green, darker than emerald, sometimes blackish green. Streak, apple green. It is an oxychloride of copper, containing about 58% of the metal; the remainder being oxygen chlorine and water.

Chalcanthite. The sulphate of copper called *bluestone* is soluble in water. It contains about 38% of copper, the other elements being oxygen, sulphuric acid and water. It is crystallized. Hardness, 2.5; specific gravity, 2.2. Luster, vitreous, and color sky-blue to darker; sometimes greenish blue. It is rare in nature. Covellite is a beautiful deep-blue copper mineral, found in Butte, Montana, and in mines of the Grand Encampment region, Wyoming. Composition CuS.

There are altogether about sixty-five copper-bearing minerals. Those that have been described are the most important; the others are too rare to be of much commercial value.

LEAD.

When pure, lead has a hardness of 1.5 and specific gravity of 11.44. It is very soft and heavy, and has a dull blue-gray color. Type-metal is lead alloyed with antimony; common solder an alloy with tin; shot and rifle balls contain a small amount of arsenic. The carbonate gives white lead, the basis of white paint. The oxides are litharge and red lead. The supply of the metal is obtained from its ores, chiefly the sulphide, galena.

Galena. The hardness is 2.5, and the specific gravity, 7.5. The luster is brilliant metallic and color bluish-lead gray. Crystallizes in cubes and has a very perfect cubic cleavage. The composition is, lead, 86.6; sulphur, 13.4. Fuses easily. It usually carries some silver, and is often worked for the precious metal. Galena is one of the commonest of minerals, and occurs in large deposits in Missouri, Illinois, Iowa, Wisconsin, Colorado and other localities. Cerussite, lead carbonate, anglesite (lead-sulphate as resulting from its own decomposition), are often found with galena.

Jamesonite and *Bournonite*. Are two rare sulphides of lead and antimony, the latter containing some copper. Jamesonite has a hardness of 2 to 3; gravity 5.5 to 6. Luster metallic, color steel-gray to dark lead gray. It resembles stibnite both in form and color. Bournonite has about the same hardness and specific gravity. It occurs in short prismatic or tabular crystals also massive. Luster metallic, color steel-gray to iron-black.

Pyromorphite. Hardness, 3.5 to 4. Specific gravity, 6.5 to 7. Luster resinous; color commonly green of varying shades, sometimes pale brown. Streak nearly white. The essential element is phosphate of lead, ·but it contains some chlorine and flourine; lime and arsenic are sometimes present. It occurs only with other ores.

Mimetite. Is essentially a lead arsenate. Luster resinous; color usually yellow. Hardness, 3.5; gravity, 7 to 7.25. Resembles pyromorphite in form. Easily recognized by yielding arsenical fumes on charcoal.

Vanadinite. Is a lead vanadate. Hardness about 3; specific gravity, 6.7 to 7. Luster resinous; color deep red, brilliant yellow and light brown. The rare element vanadium present in this ore is used in calico printing and to fix the colors in silks.

Crocoite. Lead chromate occurs in prismatic crystals of fine orange red color. The streak is deep yellow. Luster, adamantine to vitreous. Hardness, 2.5 to 3; gravity, about 6.

Wulfenite. This is a lead molybdate frequently found in the West. It occurs in square crystals or tables often as thin as a knife edge and perfectly clear; also in square pyramids; also massive. Color, bright orange yellow, brown or green; luster, resinous to adamantine; streak white; hardness, 3; specific gravity, 6.7 to 7. It is brittle subtransparent, and the fracture is subconchoidal.

Cerussite. This is the carbonate of lead and the commonest ore next to galena. Luster is adamantine, inclining to vitreous or resinous. Colorless, white, gray, or grayish black, slightly yellow, or tinged blue or green by copper. Streak colorless. Usually crystallized. Hardness,

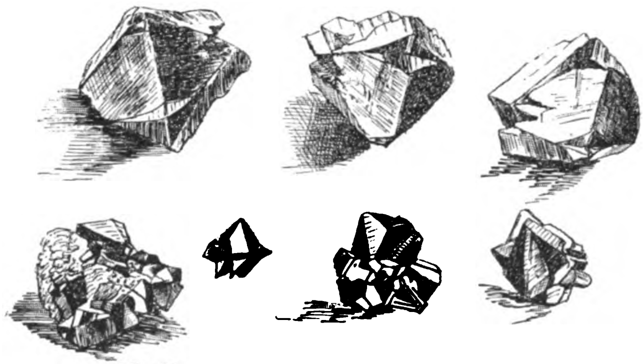


FIG. 96.—CRYSTALLIZED CASSITERITE.

3 to 3.5; specific gravity, about 6.5. Composition, lead oxide 83.5, carbon dioxide 16.5. It often carries silver, and is also valuable as an ore of lead. Occurs commonly in Colorado and other Western mining regions.

Anglesite Lead sulphate. Luster, adamantine, sometimes resinous or vitreous; color, white, sometimes tinged yellow, gray, green or blue. The masses may be drab, banded and opaque. Streak uncolored. Hardness, 2.75 to 3; specific gravity, 6.2 to 6.4. The fracture is conchoidal. It decrepitates before the blow-pipe and fuses readily to a clear bead, which, on cooling, becomes milk white. Dissolves with difficulty in nitric acid, and does not effervesce as does Cerussite. Contains about 64 per cent. of lead, the remainder being oxygen and sulphuric acid.

TIN.

Native tin occurs very rarely, if at all, in nature. The world's supply of this highly useful metal is obtained from the single ore Cassiterite, or tin stone.

Cassiterite. Is tin dioxide. Composition, tin 78.67; oxygen, 21.33. It is remarkable for its hardness, 6.5 to 7, and high specific gravity, about 7. Occurs crystallized and massive; the luster of the crystals is adamantine; color, brown or black, sometimes red, gray, white or yel

FIG. 97.

low. The massive forms sometimes have a botryoidal or veniform surface, a fibrous structure brownish color, and dull luster. It is usually detected by its great weight. Cassiterite has been found in small quanitities in several parts of the United States, notably South Dakota and California. The State of Durango, Mexico, contains a little, but the market is supplied by foreign mines. Much interest, therefore, is aroused by the reported recent discoveries of Cassiterite in Alaska.

TITANIUM.

Titanium is a metal chemically related to tin, but of no commercial value at present. The most important minerals containing titanium are the oxides rutile, octahedrite and brookite.

URANIUM.

Uranium is a rare metal first derived from pitchblende or uraninite. Metallic uranium has a steel-gray color and a specific gravity up to 9.7. When fused with iron or steel it gives toughness and hardness to a remarkable extent. The oxide of uranium imparts to glass a beautiful fluorescence of a greenish-yellow hue. It is employed in certain pigments and in painting porcelain, and is of considerable commercial as well as scientific importance.

Uraninite. In this very complex mineral, containing nine or ten elements, uranium is combined with oxygen. The Colorado specimens also contain lead, zirconium. cerium, calcium, zinc, radium, argon and hydrogen. It usually occurs in massive forms, and from the greasy or pitch-like dark color and luster is called *pitchblende.* It is occasionally crystallized in dark brown, translucent octahedrons of high specific gravity. Fracture, conchoidal to uneven; hardness, 5.5; specific gravity, from 8 to 9.7. When pure, Uraninite is opaque; color, velvety black; luster, sub-metallic, greasy or pitch-like; streak verging from brownish-black to grayish and olive green. The Colorado variety is compact, usually associated with iron pyrites, and has a specific gravity of 8.07. It is sometimes altered by the effects of the atmosphere and water into the yellow hydrated oxide, with lowered specific gravity, and a canary yellow color. Uraninite is found in Gilpin County and other parts of Colorado in pockety formation, also in the Black Hills, South Dakota. Since the discovery of radium in pitchblende a more diligent search is being made for this and the other ores of uranium.

Carnotite. Named after the eminent French scientist Carnot. Is a highly complex ore, containing, besides uranium oxide, vanadium, potash and water. There is no other mineral just like it, and once seen carnotite is never forgotten. It occurs massive, or in scaly crystals, along the minute fissures of the enclosing rock. The color is a rich yellow or orange, changing at times into a yellowish green. The loosely cohering, highly colored mass leaves a trace of color whenever touched. So far it has only been found in white or gray sandstone, and usually associated with silver and copper ores. At Paradox Valley, Montrose County, Colorado, carnotite and pitchblende occur in amorphous masses. At Richardson, Utah, a little amorphous carnotite occurs. It is usually in the sandstone, in flat-lying streaks of scale-like crystals. Besides Montrose, San Miguel, Dolores and Montezuma Counties, Colorado, and Grand County, Utah, carnotite is known to exist in Uintah, Garfield and Washington Counties, Utah.

Torbernite. Phosphate of uranium and copper. Color, bright green. Hardness, 2 to 2.5; gravity, 3.5. Translucent and sectile.

Autunite. Phosphate of uranium and calcium. Color, bright yellow. Hardness, 2 to 2.5; gravity, 3 to 3.2. Both torbernite and autunite occur in thin tabular crystals, and are sometimes called uranium mica.

VANADIUM.

When pure, is a grayish-white metal of silver-white luster. The salts of the metal are used in calico printing and in fixing aniline black on silk fabrics. The chief commercial use of the metal is as an alloy with iron and steel. It greatly increases the hardness and the malleability of steel, and thus aids materially in the preparation of sheet steel and armour plates. Vanadium is present as a pentoxide in the carnotite ores of Colorado and Utah.

Roscoelite. Is classed as a vanadium aluminum silicate. The specific gravity is about 2.9. It occurs in small scales, often in fan-shaped groups. Color, olive-green, greenish-brown to dark olive-brown. Structure, micaceous. Cleavage, perfect. Fuses easily to a black glass. Carries from 8 to 30% vanadium pentoxide. Besides San Miguel and Montrose Counties, Colorado, this mineral is known to exist in Eldorado County, California.

Vanadinite. Is a vanadate of lead combined with lead chloride. Occurs crystallized in hexagonal prisms, also in implanted globules or incrustations. Hardness, 2.75 to 3; specific gravity, 6.6 to 7.2. Fracture, uneven. Luster of fractured surfaces, resinous. Color, ruby red to light brown, yellow and red-brown. Streak, white or yellowish. It is brittle and subtranslucent. Found in considerable quantities in Arizona and New Mexico.

NICKEL.

Nickel, though formely a little-used metal, has become of much wider application in recent years. It is extensively employed now to plate many articles of steel—as knives, scissors, skates, etc.—because, unlike the steel, it does not tarnish in the air. It is much used, also, when alloyed with copper, for small coins, as the "nickels" or five-cent pieces of this country, and similarly in Switzerland, Germany and Belgium. Nickel steel has been found to be remarkably strong in withstanding the blow of a cannon ball. The white alloy called "German silver," contains copper, zinc and nickel in about the proportions of 5:3:2.

There are not, however, many minerals which contain nickel. One of these is the sulphide millerite; another is niccolite, or nickel arsenide. There are also some other rare compounds of nickel with sulphur, arsenic or antimony. Nickel is also present in some varieties of the sulphide of iron, magnetic pyrites or pyrrhotite, and this occurs in so large an amount as to be an important source of the metal. There are further some hydrous silicates containing nickel, which are extensively mined at the present time. It is interesting to note, finally, though a matter of no practical importance, that the iron of meteorites is almost always an alloy of iron and nickel, the latter metal being present to the amount of 5 to 10 per cent. and in rare cases much more.

Millerite, the sulphide of nickel, is remarkable among minerals because of its occurrence in very fine hairlike, or capillary forms. These sometimes resemble a wad of hair, as in the geodes in the St. Louis limestone, or they may be simply a tuft of extremely delicate radiating crystals, as in cavities of hematite at Antwerp, N. Y. There are also thin crusts with fibrous structure, as those from Pennsylvania. The hardness is a little over 3, and the specific gravity 5.6. It has a metallic luster and a color like that of yellow bronze, often slightly tarnished; the streak is greenish-black.

The composition, NiS, gives 64.6 per cent. of metallic nickel. Before the blow-pipe millerite reacts for sulphur, like the sulphides, and after roasting off the sulphur a small fragment will give with borax in the oxidizing flame a characteristic violet bead. The globule obtained on charcoal, after heating in the reduction flame, is attracted by a magnet, for nickel is a magnetic metal like iron, though of much feebler intensity.

Millerite rarely occurs in sufficient quantity to be useful as an ore of nickel. An iron-nickel sulphide called pentlandite is more important; polydymite is another nickel sulphide.

Niccolite, often called copper nickel, is found in masses of metallic luster; hardness, 5 to 5.5, and specific gravity, 7.3 to 7.6. The composition NiAs gives: Arsenic, 56.1; nickel, 43.9.

COBALT.

Cobalt is a metal related to nickel and often associated with it in nature. Cobalt minerals are rare; the cobalt of commerce is chiefly derived from mispickel or arsenical pyrites.

MANGANESE.

Manganese is allied to iron in physical characters and chemical relations. Like iron, it forms numerous natural compounds. Its chief use is in the manufacture of steel.

Manganite. Is an oxide of manganese. Composition is water, 10.2; oxygen, 27.3; manganese, 62.5. It occurs in prismatic crystals and in fibrous radiated masses. Hardness, 4; specific gravity, 4.2 to 4.4; luster, metallic; color, dark steel-gray to nearly iron-black. Streak, dark reddish-brown.

Pyrolusite. Manganese dioxide. Composition is manganese, 63.3; oxygen, 36.7. It is usually crystalline. Hardness, 2 to 2.5; specific gravity, 4.8. The luster is metallic; color, iron-black, sometimes bluish; streak, black or bluish-black, easily distinguished from manganite by the color of the streak, and from psilomelane by its inferior hardness. Probably formed from manganite by the loss of water and addition of oxygen. Used by glass makers; also, in making paints and varnishes as an oxidizing agent.

Psilomelane. Is a hydrated black manganese oxide. It occurs massive and botryoidal reniform, and stalactitic. Hardness, 5 to 6; specific gravity, 3.7 to 4.7; luster, submetallic; color, iron-black to dark steel-gray; streak, brownish black, shining. It contains oxide of barium and several other impurities.

Rhodonite. Is a manganese silicate of a fine rose-pink color. It is a rare mineral, though found in considerable quantities in Russia, where it is used like malachite as an ornamental stone. Occurs in the gangue of some Colorado veins.

Rhodochrosite. The carbonate of manganese is also a beautiful rose-colored mineral. It occurs in massive forms, sometimes granular and compact; also, globular or botryoidal, and sometimes in fine clear rhombohedral crystals. It is occasionally in the gangue of gold and silver veins. Hardness, 4; specific gravity, 3.6; luster, vitreous; color, rose-pink; streak, white.

TUNGSTEN.

Metallic tungsten is readily taken up by steel and forms an alloy, which is used for the manufacture of tools when great hardness is required. Tungsten ore is found in Colorado, Arizona, Nevada, South Dakota, Connecticut, New Mexico, Idaho, Oregon, Washington, California and North Carolina. The three ores of commercial importance are wolframite, hubnerite and scheelite.

Wolframite. This ore is a tungstate of iron and manganese. The analysis shows 76% tungsten trioxide, remainder iron oxide, manganese oxide and sometimes niobic acid. The hardness is 5 to 5.5; specific gravity, 7 to 7.5; luster, resinous, metallic or adamantine; color brownish-black to black; streak, between black and reddish-brown. It occurs in considerable quantities in Boulder County, Colorado, massive or crystallized.

Hubnerite. This is classed as a manganese tungstate. It occurs usually in bladed forms, rarely in distinct crystals with perfect cleavage. Hardness, 4.5; specific gravity, 7.14; color, from brownish-red to nearly black; streak, from yellowish-brown to greenish-gray. The ore exists in paying quantities in San Juan County, Colorado, Cochise County, Arizona, and at Osceola, Nevada.

Scheelite. The composition of this ore is tungsten oxide, 80.55; calcium oxide, 19.45. Crystallized. Cleavage almost perfect. Hardness, 4 to 4.5; specific gravity, 5.9 to 6.2; color, varies from colorless to yellow or brown. The streak is white. It is found in large quantities near Long Hill, Connecticut, and in limited deposits in the San Juan region, Colorado, and in the Black Hills of South Dakota.

ANTIMONY.

Has a high metallic luster, is very brittle, and its structure is crystalline. It is easily fused and forms useful alloys with lead and tin, giving hardness and durability. Native antimony is of rare occurrence. It is found in New Brunswick, California and some other places, but not in commercial quantities. It is a bright tin-white mineral. Luster, metallic; hardness, 3 to 3.5; specific gravity, 6.7.

Stibnite or Antimony Glance. This is a sulphide of antimony, and is its most important ore. The composition is antimony, 71.4; sulphur, 28.6. The hardness is 2, and specific gravity about 4.6. Luster, metallic; color, bluish-gray; streak, nearly black. Readily distinguished from galena by the cleavage. It occurs in prismatic crystals, often spear-shaped at the ends, frequently acicular and arranged in radiating groups. The crystals have perfect cleavage. It also occurs massive, sometimes compact and granular. Resembles some manganese ores, but is distinguished by being easily fusible. The antimony of commerce is chiefly derived from this ore.

MOLYBDENUM.

When pure, molybdenum is a silver-white metal, having the specific gravity 8.6. The production is not great, amounting in 1900 to only 32,000 pounds. Its chief use commercially is in the manufacture of steel. Combined with nickel it forms with steel one of the most remarkable compounds, giving to the latter improved elongation and great strength.

Molybdenite. The sulphide of molybdenum. Composition is molybdenum, 59; sulphur, 41. Hardness, 1 to 1.5; specific gravity, 4.4 to 4.8. Occurs foliated, massive, or in scales, also fine granular. It resembles graphite in appearance, but is easily distinguished from it by the bluish-gray mark it leaves on paper. When passed over porcelain the streak left appears olive green, that of graphite is gray. Luster is metallic and color is pure lead-gray. It changes by oxidation into the yellow oxide known as *molybdite*, or *molybdic ochre*. Found in British

Columbia, and in considerable quantities near Telluride, Colorado.

Wulfenite. Is a molybdate of lead. A very beautiful mineral, but not particularly valuable. See lead.

ZINC.

Zinc is not known to occur native. It is a most useful metal in the arts. The amount required annually for coating iron sheets and wire is very large. Zinc is the negative metal in the chemical electric battery. Alloyed with copper it forms brass. The white oxide is used as a paint. As obtained from the furnace in ingots, it is called *spelter.* It fuses at a low temperature, and boils at a red heat.

Sphalerite. The sulphide of zinc is its commonest ore. Called also *blende, zinc blende, blackjack.* Composition is zinc, 67; sulphur, 33. Occurs crystallized or massive. Hardness, 3.5 to 4; specific gravity about 4. Luster usually resinous; color, when pure, white or nearly colorless. With the presence of iron, which it commonly contains, the color is yellow to brown and dark brown to black. At times the color is red and the light colored varieties may have a greenish tinge. The streak is white to reddish-brown, and the powder nearly white even in the dark colored kinds. Fracture, conchoidal.

Zinc blende is commonly associated with galena and pyrite, and in Colorado frequently carries silver, and is found associated with polybasite and gray copper. While it predominates over other ores at times, as at some mines in Pitkin county, there are no zinc mines in Colorado; the zinc is always mixed with other ores. In Southwestern Missouri and adjoining portions of Kansas, zinc blende occurs in extensive deposits. Until recently the zinc of Colorado has been considered a great detriment and its values have not been usually saved. The statement that an amount in excess of $4,000,000, for 1903, was the value of the zinc product of Lake county alone, shows that the improved methods of separation are adding materially to the utilization of this long rejected metal.

Calamine. Silicate of zinc. Contains 67.5% zinc oxide, remainder silica and water. Hardness, 4.5 to 5; specific gravity, 3.4 to 3.8. Luster, vitreous; color, white or yellowish or tinged blue or green from copper. Streak, white. Fracture, uneven. Usually occurs in masses with crystalline surface, mammillary or botryoidal in form.

Willemite. A silicate of zinc. Composition is silica, 27; zinc protoxide, 73. Hardness, 5.5; specific gravity, 3.9 to 4.18. Luster, resinous; color varies. Found in masses of bright yellow or apple-green, also yellowish-brown to dark brown, in six sided crystals of a flesh-red color, and sometimes in slender prisms of a clear green. Manganese and iron are often present, replacing part of the zinc.

Zincite. Red oxide of zinc. Composition is zinc, 80.26; oxygen, 19.74. Hardness, 4 to 4.5; specific gravity, 5.5. Color, orange-yellow to deep red; streak, orange-yellow. Fracture, conchoidal. Occurs in grains or masses, occasionally in hexagonal crystals.

Franklinite. Is known to exist only at Franklin Furnace, N. J., hence its name. Contains zinc oxide, 18; manganese oxide, 16; iron oxide, 66. Hardness, 5.5 to 6.5; specific gravity, 5.6. Luster, metallic; color, iron-black; streak, reddish-brown. It resembles magnetite in appearance and is slightly magnetic. Dissolves in muriatic acid.

Smithsonite. Called by the miners ***dry bone;*** is zinc carbonate, containing approximately 52% zinc. Hardness, 5; specific gravity, 4.3 to 4.5. The luster is vitreous; streak, white; color, white, gray, green, yellow, blue, brown or red. The common form is mamillary or botryoidal masses, also stalactitic. Like all the carbonates it effervesces with acid.

CADMIUM.

Cadmium is a rare metal often associated with zinc, especially in zinc blende.

Greenockite. Cadmium sulphide. Composition, cadmium, 77.7; sulphur, 22.3. Hardness, 3 to 3.5; specific gravity, 4.8. Luster, adamantine. Color, citron-yellow to bronze-yellow. Streak and powder, yellow to brick-red.

ALUMINUM.

Does not occur native, but is one of the commonest of the chemical elements. It is remarkable for its tenacity and low specific gravity, which is only 2.5. While a constituent of most clays, it is now chiefly derived from a hydrated oxide of aluminum called ***bauxite,*** which is found in considerable quantities in the Southern States.

IRON.

The most important of all the metals from the view point of pure usefulness is iron. While many iron minerals exist in the Western States, the known deposits of hematite, limonite and magnetite, the three principal iron-producing ores of commerce, are no more than adequate to the rapidly increasing demand, much of the magnetite of Colorado is of little value because of the high percentage of titanic acid, and the limonite of the plains and foothills often carries too much phosphorus and too much silica. The heaviest and best deposits of magnetite in Colorado are in Gunnison county. The ore of the "Iron King," near White Pine of this region is remarkably pure and good. It contains no titanic acid, is low in phosphorus and sulphur, high in iron, and is without pyrites. The Calumet mine in Chaffee county had a forty foot vein yielding 63.28 per cent. iron, and only .016 phosphoric acid. It was one of the best deposits in the State.

Magnetite. Magnetic iron ore. Hardness, 5.5 to 6.5; gravity, 5.18. Luster, metallic; color and streak, iron-black. Fracture, subconchoidal. Strongly magnetic. Composition is, iron, 72.4; oxygen, 27.6. Occurs in octahedral or dodecahedral crystals, more commonly massive.

Hematite. Red oxide of iron. Composition is, iron, 70; oxygen, 30. Hardness, 5.5 to 6.5; gravity, 4.2 to 5.3. Occurs crystallized, columnar, botryoidal, stalactitic, granular, micaceous or compact. Color, dark steel-gray or iron black, when earthy, reddish-brown. Streak, cherry-red or reddish-brown. Fracture subconchoidal and uneven. Sometimes magnetic. When lustrous and brilliant it is called "Specular iron ore." It is sometimes in thin flakes and foliated, "micaceous iron ore." Often mixed with earthy impurities with no luster and a deep dull red color, then called "clay iron ore."

Limonite. Usually occurs in botryoidal and stalactitic forms; also concretionary, massive and sometimes earthy. Hardness, 5 to 5.5. Gravity, 3.6 to 4. Luster, silky, submetallic, often dull and earthy. Color of fracture surface, various shades of brown. Streak yellowish brown. The designation "bog iron ore" belongs to later deposits in swampy places, with which manganese and other impurities are usually associated. Limonite differs from hematite in composition in carrying about 14% of water. It is also called *brown hematite.*

Siderite. The iron carbonate known as siderite or spathic iron is a rather important ore. The hardness is 3.5 to 4. Gravity, 3.8. Luster, vitreous; color, light yellow to brown; streak, nearly white. It yields, when pure, 48% metallic iron. Occurs crystallized or massive, The crystals are rhombohedrons with perfect cleavage. The botryoidal and globular forms have a somewhat fibrous structure.

Pyrite: or *Iron Pyrites.* Iron disulphide. Composition: iron, 46.7; sulphur, 53.3. One of the commonest of minerals. Occurs in various crystalline forms, all derived, however, from the cube; also massive. Hardness, 6 to 6.5; gravity, 4.8 to 5.2. Luster, brilliant metallic; color, light brass-yellow. Streak, dark greenish-black. It is of no value as an ore of iron, but is used for making sulphuric acid. Auriferous pyrites is mined for the gold it carries. Other varieties carry nickel, cobalt, silver or tin, in small quantities. It is often associated with chalcopyrite or copper pyrites from which it is easily distinguished by its greater hardness and lighter color.

Marcasite. The chemical composition is the same as ordinary pyrite. Hardness, 6 to 6.5; specific gravity, 4.8 to 5. Luster, metallic; color, pale yellow; streak, grayish or brownish-black. Because of its light color is often called *white iron pyrites.* Crystallizes in orthorombic prisms and pyramids, often forms nodules, spherical forms, or stalactites; also simply massive. Frequently carries gold.

Pyrrhotite. This is a sulphide of iron which often carries from 3% to 5% of nickel and is the principal source of the nickel of commerce. Hardness, 3.5 to 4.5. Specific gravity, 4.6. Luster, metallic; color, reddish-bronze; streak, grayish-black. Occurs in hexagonal crystals and in irregular masses. Because of its magnetic character is commonly called *magnetic pyrites.* Nickel-bearing pyrrhotite is found in great abundance at Sudbury, Ontario.

Arsenopyrite or *Mispickel.* Arsenical pyrites. Composition: iron, 34.4; sulphur, 19.6; arsenic, 46. Hardness, 5.5 to 6; specific gravity, 6 to 6.4. Luster, metallic. Color, silver-white to steel-gray; streak, dark, grayish-black. Often carries silver and gold, and is the principal source of the arsenic of commerce. It often carries cobalt also.

Chromite. Composition: Oxide of chromium, 68; oxide of iron, 32. Hardness, 5.5; specific gravity, 4.4. Luster, sub-metallic; color, between iron-black and brownish-black; streak, brown. It looks like magnetite. Not valuable as an iron ore, but is the source of the element chromium.

There are some forty other iron minerals not valuable as ores of iron, but interesting to the mineralogist and the chemist for their forms, and for the rare elements which they frequently carry in combination.

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CHAPTER IX.

THE THEORY OF ORE DEPOSITS.

The origin of ore deposits is not yet an exact science. It is still in a formative stage, and with increasing knowledge, old theories are passing, widening or merging into new ones. With experience comes a steady advance in knowledge. What the present condition of the science is, may be inferred from the following discussion by eminent authorities.

The lateral secretion theory of Sandberger had for a time great influence. Its conception was that ore deposits were derived from the elements of the wall rocks of veins through the solvent agency of laterally moving waters. Sandberger showed that many of the non-metallic minerals composing the wall rock, such as augite, hornblende, mica, etc., contain, though very minutely, the precious elements found in ore-bearing veins.

Posepny did not confine the origin of ores to the immediate wall rock, or to waters acting only laterally, but contended for a more general circulation of waters, ascending, descending and lateral. It became generally accepted that a large number of ore deposits, more especially those containing gold and silver in association with a matrix of quartz, had been laid down by ascending waters, and that enrichment took place, not from the wall rock into the vein fracture, but by impregnation outward from the vein into the encasing rock.

Van Hise looked upon the underground circulation of water as one connected manifestation of natural activity, and maintained that in the formation of ore deposits all the branches of that circulation may, at different times and in divers places, play a part. Two conclusions he insisted on, viz.: that sulphide ores are generally deposited by ascending waters, and that secondary enrichment of such ore is effected to very considerable depths by the agency of descending waters.

While so far the pendulum has swayed in the direction of the aqueous agencies connected with ore deposition, an addition was made to the subject by the theory of the differentiation of rock magmas and their influence on ore deposition as advocated by Professor Vogt of Christiana, Sweden. He claimed that the normal terrestrial water circulation played a minor part in the primary formation of certain deposits, however much it may have affected their later concentration from such portions of the magma as were rich in metals along the contact with sedimentary rocks.

Kemp pointed out that the greater number of deposits of gold, silver and copper ores are near or at contact with igneous rocks, with which he believed them to be genetically connected. Every miner in the West recognizes the dependence of ore deposits on the presence of igneous rocks in the vicinity, and thus fortifies Kemp's position.

Spurr, from his study of the Yukon region, was impressed with the evidence of ore segregation afforded by a series of closely related rocks in the Forty Mile district, and claimed that the gold quartz veins of the Yukon were the end-product of rock segregation. This he explained as the result of a progressive increase in silicification by means of which a basic hornblendic granite passes into quartz-feldspar rock termed alaskite. The changes continued until the alaskite resembled a quartzite and is only distinguishable from a typical quartz vein by small porphyritic crystals of feldspar. Certain gold veins in the Yukon originated by a process of magmatic segregation, merely represented the siliceous extreme of the process, the final stage of which is marked by a magma so attenuated as to be described as highly heated water heavily charged with silica and other mineral matter, including gold.

Joseph Barrel has shown in cases of contact metamorphism, the effects of liberation of enormous volumes of gas or steam upon the sedimentary rocks penetrated by igneous masses.

W. H. Weed shows the particular conditions which render the contact of igneous and sedimentary rocks such a favorable locus for ore occurrence. This is because the sedimentary strata are made porous by thermal metamorphism comparable to the results produced by burning clay into brick. Kemp again follows his arguments for the derivation of ores directly from a magma by showing the activity which vulcanism is apt to give to thermal circulation.

S. F. Emmons, in his study of the ore deposits of Leadville, considered that the waters which deposited the ore were descending from the porphyry contact into the body of the underlying limestones, and not ascending through fissures in the Archæan granite. He also maintained that the ores were leached from the neighboring porphyry bodies, and deposited by metasomatic substitution in the limestones. As regards the ultimate source of the metallic minerals, he believed they were brought from great depths to the vicinity of the surface, or within reach of meteoric waters rather in the magma of igneous rocks than in aqueous solution; but most of our ore deposits in their present form are the result of a later concentration by circulating waters of meteoric origin. A pneumatolytic origin (that is deposition through the medium of heated gases acting on rocks) near the contact of igneous rock with limestone can be demonstrated by their mineral association, and it is very possible that some of the metallic contents of other deposits where this mineral association is wanting may have originally been separated from an igneous magma by pneumatolysis, that is presumably by precipitation from mineral fumes. The agency of circulating waters he considered as highly important.

As regards the ultimate origin of ore deposits, he thought that the greater part had probably been brought within reach of circulating waters by igneous magmas as they proceeded upwards from the interior of the earth, but that these magmas had cooled and consolidated before the concentrations had taken place, since the rock fractures which had afforded the trunk channels for the concentrating solutions were in most cases subsequent to the consolidation.

W. H. Weed argues in favor of ore bodies resulting from the gases and vapors given off from fused magmas in the process of cooling. He believed that igneous intrusions had furnished both the heat and the mineral contents, either directly as differentiations or emanations, or through the leaching of the rocks by vapors and heated waters. He offered a genetic classification of ore deposits under the following general heads:

1. Igneous, magmatic segregations.

2. Igneous emanations. Deposits formed by gases above or near their critical or condensing temperatures.

3. Fumarolic deposits. Metallic oxides, etc., in clefts in lavas.

4. Gas—aqueous (pneumato-hydro-genetic deposits, i. e., a combination of gas and water deposits), igneous emanations or primitive water mingled with ground waters.

5. Ore deposits by agency of surface meteoric waters.

6. Metamorphic deposits. Ores concentrated from older rocks by dynamo and regional metamorphism.

He made two great divisions, those of direct or indirect igneous origin, and secondly those due to aqueous agencies. Veins formed by fissure filling are accompanied by alteration and frequent replacement of the wall rock. Deposits due to the differentiation of igneous rocks are illustrated by irregular contact deposits of iron ores, copper ores, and nickel associated with basic rocks. By differentiation is meant that certain mineral elements of a rock, when in a molten state, may arrange themselves basic with basic and acidic with acidic.

Dikes represent extreme differentiation products of the magmas. Quartz veins graduate into pegmatites, aplites and alaskites differentiated from or separated out of an acid igneous magma.

By pneumatolytic action is meant the action of heated gases and vapors upon solids, the evidence of which is afforded by the mineral composition of the ores in these rocks as shown under the microscope.

Contact metamorphic deposits occur near the contacts of intrusive granitic or porphyritic rocks. The characteristic minerals associated with these deposits are—garnet, epidote, vesuvianite, specular hematite and magnetite. These metamorphic minerals result from the action of water above the critical temperature given off from the hot magma accompanied by metallic compounds together with sulphur and fluorine. These minerals were formed under pneumatolytic conditions, and their direct connection and intergrowth with the metallic minerals such as sulphides of iron, lead, zinc and copper indicate that these likewise were of pneumatolytic origin.

Pneumatolytic veins are those in which the fissures have been simply the channels for the vapors, and in which the impregnation of the country rock on each side is essentially characteristic. Pegmatite veins are of this kind, and the close relation of tourmalinic pegmatites and tin-bearing veins is well known in Cornwall. To these may be added veins carrying tourmaline and copper, and those characterized by gold pyrite and tourmaline.

Fumarolic deposits include various metalliferous minerals such as ferric-chloride, cuprous oxide and others formed in clefts about volcanic craters by gases given off from the eruptions.

Gas-aqueous deposits, according to Weed, embrace by far the largest number of the commercially valuable ore deposits of the world. The source of the metals is to be found in the vapors given off by the cooling igneous rocks, and in a minor degree to leaching of the rigid differentiated portions of cold igneous rocks by circulating waters. The waters are the vehicle rather than the agent. It is the mixture of the gases with the meteoric waters that formed the metal bearing solution.

Deposits so formed are open fissures filled with mineral crusts and replacement deposits in which the primary fracture served as the channel by which the solutions obtained access to rocks rapidly replaced by the action of particular waters.

Deposits formed by meteoric waters are those in which meteoric waters have taken the metals in solution and carried then to the place where they were deposited as ores, such as the lead zinc deposits of the Mississippi Valley.

Dynamo-metamorphic deposits show in their structure that they are the result of pressure with a re-arrangement and concentration of material.

Mr. Spurr argued that many different natural processes work together and singly to produce ore deposition. No two ore deposits have exactly the same origin. For example, the iron ores of the Mesabi Range in Minnesota were the concentrations by descending surface waters from ferrugineous marine sediments. At Mercur, Utah, the ores are ascribed directly to igneous emanations, both gaseous and liquid. At Aspen, Colorado, the ores were introduced from some foreign source by ascending hot springs, such as exist in that region to-day. The Yukon gold quartz veins he considered due to siliceous magmatic segregation. The lead, zinc, copper, silver and gold ores of Monte Christo, Washington, were deposited by descending surface waters in Pleistocene time, and from a disseminated state have been concentrated in the granitic tonalite in which most of the veins occur.

W. Lindgren was of the opinion that the majority of the metalliferous veins of the Cordilleras were due to gaseous emanations from intrusive magmas released by decreasing pressure mingling with surface waters and ascending as hot springs. He believed that a very large number of fissure veins are formed by the mingling of atmospheric waters with ascending emanations from cooling intrusive magmas. Among these emanations are water, carbonic acid gas, hydrogen sulphide and heavy metals in various combinations. There is a direct causal connection of certain fissure veins with certain intrusive masses, and these veins were deposited at high temperature. He endorsed the contact metamorphic hypothesis, saying that in such contact positions metallic minerals are deposited in such intimate intergrowth with contact metamorphic minerals that their simultaneous origin could not be doubted.

It is practically found that under certain circumstances cooling magmas will give off quantities of various substances, such as water, silica, iron, metallic sulphides, and in small quantities fluorine and boron compounds. Important results regarding the genesis of ore deposits will come from further study of these emanations.

Field work has shown that certain classes of deposits are the result of direct emanations from cooling igneous segregations in an igneous magma during the process of cooling, but it is sometimes a question whether igneous magmas, as they come from the interior of the earth, contain sufficient water to produce the phenomena observable in our ore deposits.

Suess takes the affirmative side of this question. He divides hot springs into those whose waters rise under hydrostatic pressure, and those that derive their waters from the interior of the earth, the latter being characterized by intermittence. With regard to the steam emanating from volcanic eruptions, he concludes that volcanoes are not fed by the infiltration of ocean waters, but that ocean water receives addition to its volume by every volcanic eruption.

Kemp, on the igneous origin of ore deposits, starts with the theory of contact deposits especially as produced by the action of eruptives on limestones. He goes on to show that pegmatites, which are the effects of expiring igneous phenomena, pass through veins and other forms of ores till they reach the undoubted results of deposition from meteoric waters at the other extreme.

Hitherto the significance of contact zones of garnet, vesuvianite, wollastonite, epidote and copper ores with gold, has not been sufficiently appreciated. In Old Mexico and New Mexico there are acres of garnet rock which have been produced from nearly pure limestone by the addition of silica from the eruptive, undoubtedly while highly heated. This change, as observed at Cananea and San Pedro, has followed individual beds for long distances, and no one can fail to be impressed with the enormous amount of silica which has been supplied in connection with watery vapor, or its dissociated gases and other mineralizers. Had this silica been caught and locked up near the eruptive, as it would have been in walls of almost any rock, other than limestone, we should have had very great veins produced in overlying strata. This is the method by which many veins have been formed, even though the stimulating eruptive is not exposed to sight.

Mr. Lindgren has shown that after several geological periods or even eras of no vein formation, suddenly and for a brief period following igneous outbreaks, vein formation became very active. It then died away. He attributes this activity of vein formation to the eruptive rock.

Eruptive rocks accompany great upheavals and extensive fracturing. It may be maintained by some that the eruptive rocks have merely furnished the propelling energy and the vein minerals to circulating meteoric waters, but Kemp believes them to be not only the source of the energy and the minerals, but also largely of the watery vehicle itself. Thus we find no vein formation through vast extents of time, though conditions were favorable to meteoric waters, when suddenly the outbreak of eruptive rocks starts it up. It may be said that outbreaks of eruptive rocks and great upheavals imply extensive fracturing of the rocks favorable to circulation of meteoric waters which following down the fractures, gather up their burden of ore and gangue and return to the surface, expelled, perhaps, by the heat of the eruptive. The period of vein formation would then last until the cavities were plugged and the meteoric waters no longer found entrance or exit. But there are larger areas of fractured rocks or fractured districts in old long-cooled eruptives that show no extensive vein formation, although meteoric water was abundant and had easy access to the rocks.

Hot springs have undoubtedly been the chief agents in the primary deposition of ores and gangue minerals in veins. It is noteworthy that while many deep mines in regions of abundant meteoric waters are dusty and dry, in regions of comparative aridity the few deep and wet mines are in areas of expiring vulcanism. Enrichment may take place near the water level or for short distances below it by the leaching of the upper portion in the descent of the surface waters. It is also true that the richest ore in mines may lie from three thousand to three thousand five hundred feet down the slope or shaft as at Przibram and Grass Valley.

Mr. Ransome quoted Professor Vogt that the "precise tracing of the boundary between eruptive after-action and the work of the underground waters is a labor of the future." He insisted on the grouping of accepted types of known origin. The use of the critical temperature in the argument implies that contact-metamorphism ceases, and entirely different processes come into play the moment the magma cools below 365 degrees C., but water still exists as vapor below the critical temperature provided the pressure be not excessive; and it has yet to be proved that substances given off from the magma above the critical temperature are the only agencies capable of producing the minerals characteristic of contact zones.

An ore body implies a local concentration of materials elsewhere very sparingly present in the rock. It can not be explained as the result of crystallization of material already provided in the presence of some mineralizing agent given off from a contiguous body of molten magma. It implies extensive transfers of material difficult to ascribe entirely to pneumatolytic processes, particularly as one of the characteristics of ordinary contact-metamorphism is a very slight change in the chemical composition of the metamorphosed rock.

Mr. Ransome considered that most ore bodies were formed after the solidification of the eruptive rocks with which they are associated, and that the principal agent in their concentration and deposition has been meteoric water. He cites a number of cases where the veins are distinctly later than the eruptive rocks. Though pneumatolysis may have had some influence on ore deposition, he maintains that the action of meteoric waters, usually heated and rendered physically and chemically active by masses of intrusive rock, is the most important of all agencies.

T. A. Rickard, reviewing the evolution of our knowledge of ore deposits, showed that in early days the occurrence of ore was imputed to vague igneous agencies and unknown gaseous emanations. Then followed the recognition of the effects of water in depositing minerals within the earth's fractures. This idea culminated and was followed by a theory of igneous agencies until the aqueous factor is limited almost to the surface. Instead of a depth of six miles or more, as claimed by Van Hise, the advocates of magmatic differentiation now propose to confine the agency of free water to a shallow strip somewhere near the earth's surface. The theory of aqueous deposition of ores is thus threatened by an igneous intrusion of a very violent kind. The agency of water was at one time underestimated, that of magmatic differentiation unrecognized. Lately, and as each branch of the subject has been elaborated, enthusiasm has carried its advocates beyond bounds.

The swing of the pendulum is just now on the igneous side, by and by it will move back to a compromise of views, so that with more thorough elaboration of this many-sided problem, a more comprehensive theory. may be attained.

Any one familiar with ore occurrences in the West will admit that there is an intimate connection between ore deposits and igneous rocks. In Colorado ores occur in every geological terraine from the Archæan to a Tertiary conglomerate. But there are few mining districts in which igneous rocks are not found in close association with the ore deposits. The deposition of ores represents the results of that thermal energy which is, as it were, the dying breath of volcanic activity; and the dikes, sheets, cores and laccolites were factors in stimulating the concentration of mineral solutions. Not that the igneous rock was the direct ore carrier, but that it energized the chemical work of the solutions and opened a passage way for such solutions whereby they reached the locus of their deposit. The igneous matter brought the metals within the region of water circulation, and the actual concentration of ore which is exploited by man to-day was the result of the underground water system.

As regards the influence and depth of water circulation, data afforded by mine workings indicate that a condition of rock saturation does not persist indefinitely downwards, but that there is a water zone extending from ground water level for a further depth of several hundred feet. Below that horizon whatever free water exists is confined to definite channels, that is, vein fractures similar to those in which we find the ore to-day. At depth we encounter Vulcanism. Thus, we have the elements of a circulating system: heat at the base; a series of channels leading to the surface, and a reservoir of cold water at the top. Superheated water vapor serves as the main propelling force, nor is it likely that the water is wholly of meteoric origin. Much of it, like other factors in vein formation, is indirectly traceable to the sources of eruptive activity. Underground waters travel along fractures and that system of fractures called "shear zones" which afford no continuous free passage but a path of circulation, is sought out with difficulty and followed with infinite patience.

The deepest metal mines and coal mines are proverbially dry. It is useless, therefore, to speak of an indefinite water saturation. The heavy inflow of water in mines coincides with a comparatively shallow zone, and the bodies of water encountered underground are eventually pumped out.

Van Hise, in his article "Some principles controlling the deposition of ores," stated: That the metals of some ores are derived directly from recent adjacent igneous rocks. That the ultimate source of all the metals of ore deposits is the igneous rocks. That igneous rocks have an influence upon ore deposits by contributing to them both metals and solutions. That igneous rocks produce important effects by heating solutions of meteoric origin, and in forming the openings which may be followed by such solutions.

C. W. Purington views the question as follows: The distribution of ore deposits is to the mining engineer of more practical importance that the discussion of the origin of ores. In recent years the minute and accurate testing of rock and rock areas remote from metalliferous veins has given convincing evidence of how wide-spread is the distribution of gold. Mr. Luther Wagner has shown that granite, syenite, basalt, and diabase for igneous rocks, and even Carrara marble and San Francisco bay-mud for sediments contain gold in appreciable quantities. It would seem as though the distribution of gold were practically universal. Mr. Spurr believes that the siliceous relique of large igneous magmas as exemplified in the consolidated portions now visible at the earth's surface, is more prevalent than has been supposed. Further, he maintains that in any large area of rocks which is characterized by the occurrence of metalliferous deposits, the distribution of the gold-bearing veins is connected with the granite or siliceous rather than with the more basic or iron-bearing portions of the mass. He says, further, that certain portions of the cooling mass may, if they find a sufficient opening, take the form of very siliceous dikes, which by the disappearance of the biotite and obliteration of the feldspar, become what he has called "Alaskite;" and that these Alaskites pass into quartz veins containing precious metals as direct products from the cooling magma, and among the metals, notably gold. He traces the origin of certain quartz veins directly from igneous magmas by a process of magmatic segregation, and derives an auriferous quartz vein from an igneous siliceous dike.

The late Thomas Belt, in reference to the igneous origin of veins, said: "The fusion of rocks in the bowels of the earth and their subsequent consolidation supply the requisite conditions for the rending open of the superincumbent rocks and the filling of the rents so formed with fluid matter, varying in composition according to the comparative depth from which it has been projected." Mr. Levat, a French engineer in Siberian gold regions, observes that the bedrock is a clay schist lying between two masses of granite which are connected by a dike of aplite. The richness of the placer he attributes to the erosion of the aplite. He thinks the aplite was mineralized by a process contemporaneous with the disappearance of the mica from the igneous rock, and defines aplite as a granite without mica.

Such cases are cited as illustrations of the apparent direct connection of gold with granitic rocks in origin.

There appears to be a genetic connection between siliceous rocks and gold. Diorite is a rock favorable to gold, but Mr. Purington thinks that neither diorite nor granite alone, without the accompaniment of the more basic rocks, are generally favorable to the segregation and sub sequent deposition of gold.

"Pegmatites," says Kemp, "grade insensibly into quartz veins." In Clear Creek Cañon, Colorado, pegmatites occur at times like true fissure veins with well-defined walls. Purington considers pegmatites as segregations from an enclosing mass rather than as true veins. They grade into the containing granite by a finer and finer crystallization. He claims that nearly all large quartzose gold-bearing veins are accompanied by basic dikes, and cites the Alaska Treadwell Mine, where the mass of sodium-syenite has been mineralized throughout consequent on the intrusion of a much later dike of basalt. The Treadwell exhibits the features of a shattered and subsequently cemented and impregnated mass. So, in the quartz gold-bearing veins of Perm, Russia, there has been a permeation to an extraordinary areal extent of gold-bearing solutions into a previously shattered and fissured country, due to the presence of basic dikes. The Ural gold deposits also follow basic dikes, especially peridotites, and at Miask there is an increase in placer gold and vein gold from the granites, as we go east into a region of green-stone schist, porphyrite, serpentine and peridotite. Gold and platinum are closely associated in certain placers. The platinum is derived from the basic peridotites, and the gold chiefly from gold-quartz veins in siliceous rock or granites.

At Haile, North Carolina, is a region of hydro-mica schists now silicified by the influence of ore-bearing solutions. The principal mine workings closely follow dikes of diabase, the best ore chutes occur in silicified slate bands directly in contact with the dikes.

To the layman it might seem as though any decision about the origin of veins and ore deposits was at present

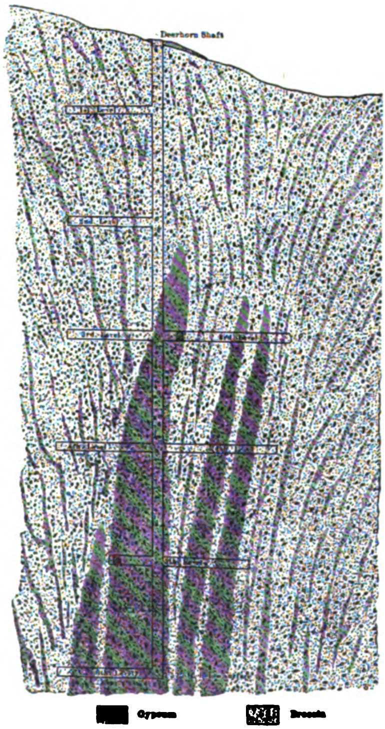

FIG. 98.—FUMAROLE DEPOSITS, CRIPPLE CREEK.

far away, when so many doctors disagree; but reviewing all that has been said by these able investigators and close observers, there does not seem to be an irreconcilable discrepancy between them, nor any reason why a combination might not result in a comprehensive theory.

May we not infer that all veins were not formed or filled in the same way, but that in different ore deposits conditions were varied. Some veins have been formed wholly by hot alkaline waters, either ascending or descending, or lateral. Some may have had steam and various gases associated with the deposition, and in others there may have been results from a differentiation of the materials of a mother magma accompanied by hot water, steam and gases, or even without these. (Fig. 99.)

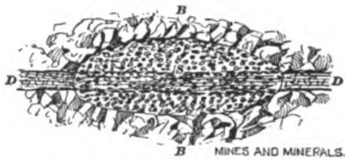

FIG. 99.—SECTION OF THE ANNA LEE ORE DEPOSIT, CRIPPLE CREEK.

In the West, at least, two factors seem to stand out in great prominence. They are, heated waters, and the accompaniment of igneous rocks and eruptive agencies. We do not know of an ore deposit of any magnitude in the western country, or any mineralized region of importance, but has its eruptive rocks and direct or indirect evidences of igneous agencies in the vicinity. You may travel through miles of rock and sedimentary formations exposed in the various cañons, and will find all barren until signs of eruptive agencies and igneous rocks are perceived, then almost infallibly ore is present. Again you may pass over miles upon miles of consolidated lavas and not see a trace of ore deposition. So more than one circumstance seems necessary for the favorable occurrence and deposition of ores.

As an illustration of the formation of veins at the present time, by ascending hot waters, the classical example of Steamboat Springs, Nevada, may be cited. These springs are situated on a line of fissures extending in the direction of the Comstock vein, clouds of steam issue from many vents over a bare rocky space, half a mile long, in a narrow valley with volcanic ridges on either side. The vents are separate, but occur in parallel lines, showing that they are connected by fissures. The fissures traverse a continuous crust of deposited quartz which is half a mile long, nine hundred feet wide and thirty feet deep. Some fissures are open, some partly filled with quartz with water issuing from a narrow crevice in the middle. Some are wholly filled with quartz, and have become true fissure quartz veins. Some of the larger fissures are a half mile long, a foot wide, open and parallel, about twenty-five feet apart and descend downward to the quartz crust thirty feet, and can be followed no further because quartz has been deposited in such abundance as to cover up their original vents in the underlying country rock. Water does not issue from all the fissures, but can be seen and heard eight or ten feet below, in violent agitation from steam and carbonic acid gas. The quartz filling in the hottest parts is gelatinous, in others spongy, and in others hard, or in layers of agate, chalcedony or sugar quartz, and the same banded or ribbon structure often observed in fissure veins, resulting from successive depositions on the sides of the fissure by water solutions. The quartz in these fissures contains sulphides of iron, and copper, cinnabar and even free gold. The metallic contents, as in old fissure veins, are in much less proportion than the quartz veinstone. The country rock below this fissure crust is a volcanic rhyolite lava, pierced at one point by a dike of basalt. The hot springs and steam vents are probably the weakened manifestations of volcanic activity that occurred most violently when the basalt was erupted. Here we seem to have the conditions of a fissure vein forming before our eyes, and explaining to our vision the way in which certain fissure veins have probably been formed in the past.

CHAPTER X.

PLACERS.

Gold and other minerals are found in surface deposits of sand and pebbles resulting from the breaking up of older rocks, and the distribution of the detritus in what are called "placers" or gulch mines. These deposits are of comparatively recent origin, dating from the Tertiary or Glacial epochs to the present and are found in nearly every mountain ravine in Colorado, or in the banks of our principal streams. The gold is found among

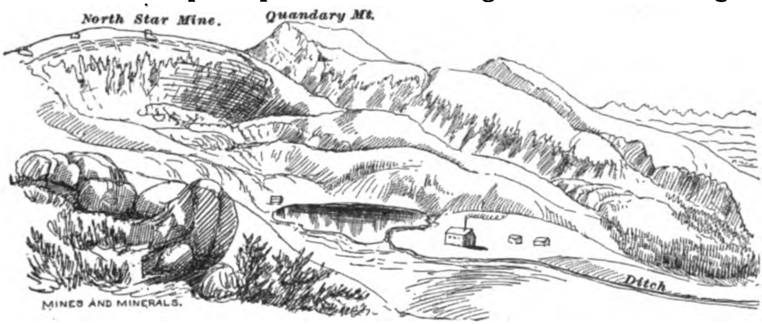

FIG. 100.—WATER POWER OF AN UPLAND PLACER IN CIRQUE, NEAR MOUNT LINCOLN, COLORADO.

the pebbles and sand in grains, flakes, dust and nuggets. It is derived partly from broken up gold-quartz veins in the older rocks, and from the disintegration of the constituent minerals composing the mass of the rocks, which contain minute particles of gold in their elements, and also from free gold in the rocks themselves. Platinum

FIG. 101.—GLACIAL MORAINE PLACER BEDS AT HEAD OF SOUTH PLATTE RIVER, COLORADO.

and tin are found under similar conditions, but these metals have not been discovered in any quantity in Colorado.

Situation. Placers may be situated high up near the summits of the mountains in *cirques* or glacial-formed amphitheatres (Fig. 100), or on the banks of a cañon or stream, in rolling, hummocky ground formed by glacial moraines, in the bed of a creek, on benches and terraces at various levels above the present stream, or strewn over table lands and broad agricultural areas along the base of a mountain range.

Only limited portions of such placer grounds may be available. Both the material carrying the gold and the gold itself are usually very unequally distributed.

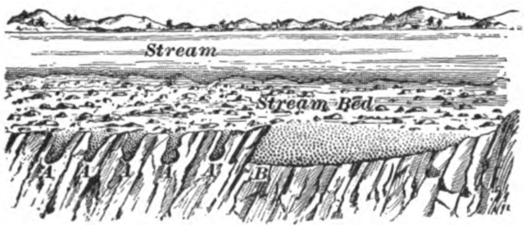

FIG. 102.—GOLD PLACER DEPOSIT IN CAVITY OF UPTURNED BED-ROCK SCHISTS.

Character of Gravel and Minerals. The gravel is usually a mixture of fine and coarse material, of small and large pebbles up to boulders a yard or more in diameter, a heterogeneous collection from all the rocks of the surrounding country. Besides representatives of a great variety of rocks and geological formations, there is often a number of minerals of high specific gravity and insolubility derived from veins and the disintegration of rocks containing them, such as garnets, tourmalines, beryls and

FIG 103.—PLACER BEDS, ALMA, SOUTH PARK, COLORADO.

occasionally such precious stones as topaz, rubies and even diamonds. Such metallic minerals as platinum, (native) tin (oxide) and lead (galena), also occur, together with a considerable quantity of magnetite, known as "black sand," which may vary in size up to a pebble as big as a man's fist or larger. All these minerals have remained in the placer because of their insolubility and high specific gravity. Minerals of less gravity would have been washed away, those of greater solubility would have been dissolved by the various acids known to have existed at one time or another in a placer formation. This latter,

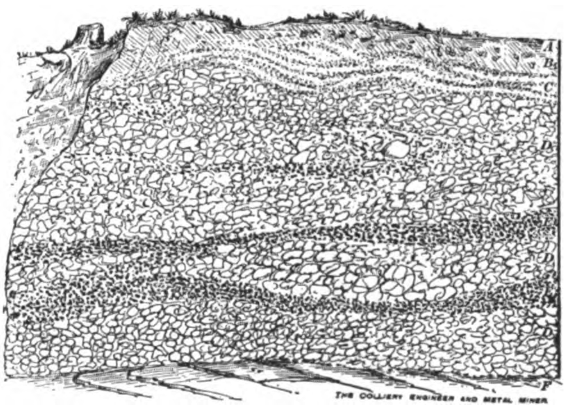

FIG. 104.—SECTION OF PLACER BANK AT ALMA, SOUTH PARK.

perhaps, is the reason that silver rarely occurs in gravel deposits.

Distribution of Gold. In these banks of heterogeneous material gold may occur distributed more or less throughout, or concentrated at various levels from grass roots to bed-rock. Rich deposits are sometimes found at grass roots by, it may be, the uprooting of a tree.

Some zones or spots are much richer than others. No hard and fast law will apply to the distribution of gold in placers, each must be studied individually. On bed-rock, or immediately above it, is usually the richest concentration, while considerable gold may be found in the cracks and crannies of the bed-rock itself. Zones marked by rusty material, *black sand* and minute garnets are commonly favorites. Belts of fine clay known locally as *pipe clay* are often barren. Gold is sometimes in the finer gravel, but more often in the coarser material near the bed-rock. Beds of pebbles and sand cemented by iron oxide are not infrequently met with at various levels. Upon and in these so-called false

FIG. 105.—PLACER BED SHOWING LOCATION OF "BLACK SAND" ON BEDROCK.

bottoms gold may also be found. They must be passed through to reach true bed-rock.

Depth. This may be from a few inches to several hundred feet, depending upon the circumstances under which the placer material was laid down, and the amount of erosion it has suffered since. The latter will depend upon whether the placer was protected by a cap of lava, or its material unusually compacted and hardened by pressure or silicification or by metamorphic agencies.

Structure. The top or surface of the placer may be a bed of peat or soil several inches or several feet in thickness containing few or no pebbles. Below this are the so-called gravels. The coarseness of the material and the size of the boulders commonly increases towards the bottom and in the vicinity of bed-rock. Here and there a huge boulder may appear by itself in the middle or in the upper part of the placer bank amidst comparatively fine material. Splashes or irregular cross-bedded bodies of gravel and sand occur now and again, indicating torrential or rapid water action. Banks of pipe clay may occur either locally, or, as in some of the California placers, traceable in a continuous band for thousands of feet. These may indicate deposition in still waters, or, again, may represent the fine attrition clay found beneath a glacier. A placer formed entirely by glacial action would have its boulders subangular, whilst that deposited by a stream would have them well rounded, and more or less stratified. On general principles the gold occurring in the former would be coarser than that found in the latter.

Bed-rock. The bed-rock underlying a placer is the country rock of the vicinity. Commonly it is more or less decomposed. If uptilted and on edge its laminæ, as well as its joints and crevices, form ready receptacles for the gold held in suspension or working down through the loose material above. Uptilted slates, especially if they dip with the downward direction of the stream, act as natural riffles to catch the gold. If the bed-rock is inclined against the direction of the stream, results are not so favorable. A coarse conglomerate will catch and retain more gold than a fine-grained sandstone. If such beds alternate with seams of impervious shale, the latter may act as a floor through which no gold passes.

A region peculiarly favorable to the occurrence of such deposits is like that characteristic of the rich placers along the Pacific coast of Alaska, the Kootenai, Oregon and California. Here upturned, decomposed slates and

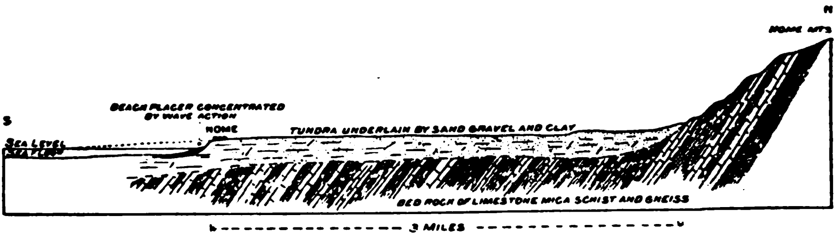

FIG. 106.—SECTION OF GOLD DEPOSITS OF NOME.

schists carry numerous veinlets and lenses of gold bearing quartz, and are traversed by decomposed dikes of serpentine and other volcanic rocks. The dikes and cross veins not infrequently act as dams and retain the gold. (Fig. 106.)

By the working of a placer important ore bearing veins have often been discovered in the bed rock and subsequently developed into rich mines.

Source of Placers. While many placers are formed from material brought from a distance by glacier or stream, others are derived from materials close at hand. Some so-called placer workings are on the oxidized outcrops of veins and gold-bearing rocks, or on the detritus that has moved down a little way from these by the action of freshets, frost or gentle local erosion. Here the gold may be crystalline and show few signs of being water worn. The detritus is for the most part subangular, few water-worn pebbles appearing. Such surface deposits are usually shallow, though often exceedingly rich.

Placer mining usually precedes *reef* or *ledge* mining, and placers are often traced to a source and the gold-bearing vein found in place. Sometimes a peculiar or predominating rock pebble may be traced up to the cliff whence it came, and a gold-bearing ledge or reef discovered. The general configuration of the country may

FIG. 107.—SOURCE OF PLACER MATERIAL. GLACIAL BASINS, HEAD OF PLATTE RIVER.

often suggest to the shrewd guesser the source of some of the placer gold. Seldom, if ever, is a large placer derived from the robbing of any one vein, but from a wide area of ore-carrying rock. These may enclose distinct veins or contain in themselves, like the Leadville pyritiferous porphyry, considerable gold elements. So a rich placer region, as in portions of Alaska, often disappoints the prospector looking for big quartz leads. The gold of these regions is derived much more from numerous small veinlets and lenses than from any great reef in place. Finally the components of a placer usually show that the

FIG. 108.—MINERS HYDRAULICKING OUTCROP OF AN OXIDIZED GOLD VEIN.

material was brought to it from many side canons and gulches as well as down the main stream.

Consolidated or Fossil Placers. The crystalline rocks are more generally productive of placers than those of sedimentary origin. The latter, however, may, at times, represent old consolidated or "fossil placers," and carry gold. Ancient hard conglomerates, like those of the Black Hills, may once have been placer grounds. Many of the placers of Alaska are frozen solid and have to be thawed or blasted out.

Dry Placers. For profitable working in a placer region water is as essential as gold. Many districts have old dry placers, but from lack of water in the vicinity they are of no value. The so-called "dry-washing" machines for separating and saving the gold without the use of water have not as yet proved a commercial success. These dry placers in arid regions were, in some cases, formed by ancient but now extinct rivers and other bodies of water. A large proportion of them, however. are from debris washed down from ore-bearing rocks and veins by sudden and intermittent freshets. They are characterized by their superficial nature and by the number of false bottoms they are liable to contain before true bed-rock is reached.

Sea Beach Deposits. Beach sands sometimes contain gold in a finely divided state in layers of magnetic iron sand, which by concentrating action of waves and tide is separated from the lighter quartz sand. By the wash of the water the gold layers are sometimes exposed and again covered by the non-auriferous material. With the gold and like it, only more compact, flakes of platinum are found. As the tides continually alter the position of the gold-bearing layers, it is necessary to prospect daily for the richest spots.

Beach mining has been carried on in various places along the Pacific Coast from Cape Mendocino, in California, to the Unqua River, in Oregon.

The beach deposits of Alaska are described in the chapter "Placer Mining in Alaska."

General Remarks. Ponds or small lakes, whose basins were hollowed out by glaciers as well as deep potholes scooped out at the base of an extinct water fall. sometimes carry gold, but are more often barren. In the case of potholes the fine gold instead of dropping to the bottom was mostly carried over the rim by the seething waters, and found lodgment further down the stream, only large nuggets were of sufficient weight to sink to the bottom.

The courses of present streams and of ancient channels form placers. The latter may be crossed by newer channels and run in different directions. When two old channels or dead rivers meet and cross, the line of junction or crossing is often rich.

FIG. 109.—PLACER GOLD DEPOSITS IN POTHOLE IN BEDROCK.

Gold deposited by a stream may be in hollows behind a bar or rock and in little coves where the current slackens and makes still water. It will be found more frequently in bars or points than in deep pools or bends.

Gold in gravels may be in layers, the one above the other. The lowest layers of each separate period of deposition are the richest. Sometimes it lies in thin layers of sand or pipe clay on the surface of the bedrock as well as in crevices of the more or less rotten bedrock itself. (Fig. 102.)

Alluvial placers may be rich when the current of the stream is interrupted by diminution of fall, by sudden change of direction, by entrance of a tributary stream or by bars and eddies.

Gold may occur in well-defined ancient river beds under a capping of lava, which has filled the channels of the rivers in past ages. These so-called deep leads are characteristic of California.

Again, gold may appear in isolated mounds or hillocks, the remains of such channels, which being unprotected by lava have been broken up by the action of the elements and partially eroded. Also in basins or flats that have received the wash of these disintegrating rivers; and in low rolling hills near the base of the ranges and beyond the reach of the lava flows.

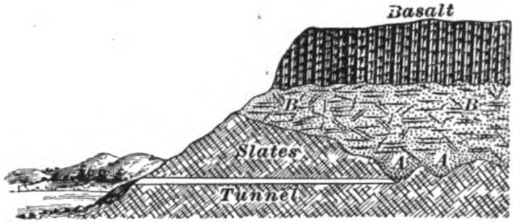

FIG. 110.—OLD GOLD-BEARING RIVER BEDS, CAPPED BY BASALT, CALIFORNIA.

In deep leads capped by lava, waters percolating through the lava become alkaline and silicious. On penetrating the loose placers and old river channels they cement the gravels by silica held in solution and silicify the placer drift wood. Hence gold is found associated with the fossil wood upon which it was precipitated before silification, and is more or less distributed in the silicified or fossilized placer.

Where a lead or old channel becomes very narrow and dips steeply the gold is sparingly distributed, because here was the course of a rapid current. If deposited at all it will be in holes and behind ridges, and will be coarse.

A favorable condition for deposition of gold is a comparatively narrow channel with a compact, permanent bedrock suitable for the concentration of gold on its surface, and ridges or bends in the course of the channel, which by causing a partial arrest in the rapidity of the current, allow the particles of gold to reach the bottom and hold them there when once they have settled.

A valley of erosion formed entirely by the action of running water, since the glacial period, may be more favorable for placer gold than one carved out altogether

FIG. 111.—DEEP PLACER BEDS OF CALIFORNIA.

by glaciers. In the former case there is a bottom or bed of hard rock. Its transverse section is V shaped, and therefore fitted for the concentration of heavy particles. When comparatively full of water the numerous bends form eddies in the down-flowing stream, when a longer time is allowed for the settling of the floating particles. As the current cuts across many formations in its course the bed of the stream will have transverse ridges, which will have caught and retained some of the gold.

In glacial carved valleys the courses are straight and the bottoms broad and smooth. The moraine material with which they are filled has not gone through the sifting and jigging process to which gravel is subjected in the bed of a stream.

Very large and abundant boulders, owing to the difficulty of removing them, are often a serious obstacle in getting out the gold. More than one reasonably promising placer has been abandoned from this cause.

Terraces on hill sides high above the present bed of the stream are ancient placers left either by glaciers or older streams before the river cut down to its present channel level, where it still deposits gold. (Plate 9951.)

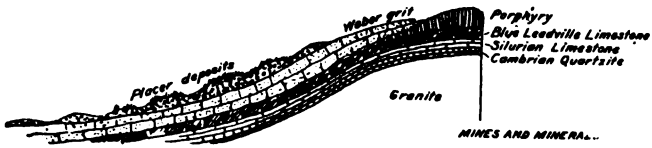

FIG. 112.—PARTIAL SECTION OF MOSQUITO RANGE ON EAST FLANK.

A region that carries much gold disseminated in its rocks and veins and shows much float on the surface is likely, in its valleys and water courses here and there, to give good placer ground.

The great "Blue-Lead" of California is a good example of an ancient river course. It runs parallel with the main divide of the Sierra Nevada and is traceable for from sixty-five to one hundred and ten miles, and is crossed by living modern rivers at right angles. It was discovered by following up surface workings, whose richness increased as the Blue-Lead was neared and ceased when it was passed. The deposit is three hundred feet deep of gravel, bowlders and pebbles of a prevailing blue-gray color. The bedrock is of slate.

Placer gold may occur in flat or leaf form or in ragged masses along or adhering to bits of quartz. If traveled far it is water-worn, if from veins nearby it may still retain its crystalline character. If near its source it is liable to be coarse, if far distant, flour or shot gold. Sometimes it is coated with iron oxide and is dull in color. This iron coating may prove a hindrance to amalgamation.

Placer gold is usually purer than vein gold and has less alloy of silver.

CHAPTER XI.

EXAMPLES OF PLACERS.

PLACER MINING IN ALASKA.

(From Alfred H. Brooks, U. S. Geological Survey.)

Placer gold has a wide distribution in Alaska. It has been found near the southern boundary of the Territory and at various localities northward as far as Bering Strait. The zone has a maximum width of three hundred miles, stretching northward from the Southern Pacific Coast, crossing the Arctic circle and bending westward to the shores of Bering Strait.

The source of the gold is in small quartz veins and stringers, which are disseminated in the metamorphic rocks. Iron pyrite is the commonest mineral found in association with the gold in the parent rock. The gold occurs both free and combined with the pyrite. Quartz is a common gangue, associated with some calcite. Galena is frequently associated with the gold-bearing quartz veins, and chalcopyrite and arsenopyrite have also been found.

In nearly every case the gold has not traveled far, and can be usually traced to a source within the basins where it occurs. The placer gold owes its present position entirely to the erosion of the bedrock in which it was formerly disseminated and to the sorting action of water and gravel. It was not brought by glacial action, because all the placers of Alaska are outside of the limit of former glacial activity. The dense coating of moss makes bedrock prospecting difficult and uncertain.

The auriferous deposits from which the placer gold is derived occur in metamorphic rocks of various kinds, including schists, limestones, quartzites and altered igneous rocks. The mineralized metamorphic beds of southeastern Alaska are probably Mesozoic and older; those of the Yukon are pre-Cambrian; those of the Seward Peninsula are Paleozoic.

The mode of formation and concentration are the determining factors of richness of the placer deposits. In the simplest formation the gold has been washed from the parent rock and concentrated in the beds of streams, mingled with other detrital material. Many of the rich placers are due to secondary concentration by the erosion and dissection of an older placer, and the re-concentration of the gold contained therein. This process of double sorting is the chief cause of the bonanzas which are not uncommon in the Alaska placer mines, and accounts for the irregular distribution of the gold often within a single topographic basin.

A common form of enrichment is the dissection of an auriferous gravel bench of the slopes of a stream valley by a tributary stream. This tributary stream carries gold derived from the bench to the main stream, where it is mingled with the gold of the main stream with consequent enrichment of the placers located at and below the junction of the two streams. Sometimes the gravels of an old drainage system lying at considerable altitude above the present stream floor are dissected by the present waterways, and the gold contained in the older gravels is thus re-sorted and re-concentrated. Another form of concentration is by wave action. In this the waves concentrated the gold which had been deposited in the gravel of the coastal plain. So were the rich placers of the Nome beach formed.

Prospectors should seek to trace old drainage channels and pay special attention to the junction of these with the present streams. From stream channels attention should be turned to the benches and terraces above them.

THE NOME PLACERS, ALASKA.

(By A. A. Brooks, U. S. Geological Survey.)

The Nome mining region is an ill defined area in northwestern Alaska, near the entrance to Norton Sound. Mountain ranges form the backbone of the peninsula, but the coast line is even and bordered by low tundra plains. The beach is low and smooth and is swept by a heavy surf. Two hundred yards from the surf is a sharply cut bench, towards which the beach rises gradually. From the edges of this terrace, which is twenty feet high, the moss-covered tundra extends inland, rising two hundred feet in five miles. (Fig. 106.)

The principal rocks are limestones and graphitic mica-schists carrying garnets, magnetite, and iron and copper pyrites, with small mineralized quartz and calcite veins. True igneous rocks are absent.

The tundra plain slopes gently from the base of the mountains to the sea. It is formed of gravels, sands and clays, and was laid down in a shallow sea or bay when the land stood lower than at present. Under the dense spongy growth of moss and grass is a layer of dark brown peat from two to twenty inches thick. This rests on stratified sands and gravels, including a white sand similar to that of the beach. There are also layers of ruby and black sand at intervals carrying gold. These rest on a blue or yellowish clay of tough impervious character termed *bedrock* by the miners. The true bedrock is a soft sandstone or mica-schist underlying the tundra at a depth of twenty to forty feet. The sea sorted and reduced this material. During the elevation which resulted in the formation of the present coastal plain the shore line gradually receded, so that the waves successively worked over the materials of different portions.

The carbonaceous clay beds were off shore deposits. The gravel terraces on the mountain slopes have a similar origin to those of the plains.

Coarse gold is confined to the creek and gulch diggings, and is from the size of a pin's head to nuggets weighing up to twenty and twenty-five ounces. Much of the gold is the size of No. 3 shot. The gravels of the gulches and smaller valleys represent the stream deposits during the period of deposits of the coastal plain. They lie on bedrock. There is no evidence of glacial action or of an ice-born origin of the gravels. The gold is rounded and waterworn. In color it is dull, resembling tarnished brass. Small vitreous quartz masses are found attached to the nuggets. The pay streak is of varying thickness, but the gravel carries gold from the surface down. The gold is not evenly distributed but gathered into zones. The pay streak marks an earlier channel of the creek. The gravels are medium fine, and the pebbles are chiefly limestone and mica schist with calcite and quartz of vein origin, all mineralized. Ruby and black sand, consisting of garnets and magnetite, abound. These having high specific gravity are concentrated with the gold in the pay streaks.

In the beach deposits is fine gold sand and flake gold. The beach gold is bright like brass and of irregular shape, usually flattened with rounded surfaces, showing the grinding action of the surf. This beach gold occurs in a strip of fine gravels and sand from one hundred to one hundred and fifty yards wide, parallel to the shore, which has been traced for ten or fifteen miles. Above the clay are stratified black sands, fine gravels and layers of shingle. Gold occurs in patches on bedrock. The pay streaks may be from a foot to several yards wide. Their axes lie at right angles to the shore line. Gold has been found from the grass roots of the tundra to low tide. The deposits extend seaward. The richest streaks of the beach deposits lie close to the clay bed; others are in the layers of ruby and black sand at the base of this formation. Pay dust from the sand layers consists of fine garnets and magnetite with vitreous and rose quartz grains. In the gravels are found rounded fragments of iron and copper pyrites yielding 0.12 ounce gold with a trace of silver.

The waves are not constantly adding gold to the beach placers by bringing it up from the depths of the ocean, as some suppose. The beach deposits are a concentration of the gold carried by the gravels and sands of the tundra. The waves are continually cutting away the base of the bluff that bounds the tundra on the seaward side. As the material is thus cut away, the gravels and sand are carried seaward by the undertow, while the gold because of its greater weight is left on the beach and works its way downward more or less in the loose sand near the water line.

The source of the placer gold is local. It is probably traceable to the heads of some of the gulches. The gold may not all have been concentrated in veins, but disseminated through immense masses of rock broken up by erosion, and redeposited by streams and waves. The gold in the tundra is finer than that of the gulches because it has been transported a greater distance, and that of the beach where it has been subjected to the wearing of waves is finer still.

The life of a gold nugget in this region is as follows: When the nugget is freed from the parent rock by disintegrating agencies it has an angular form. It is washed down the gulches and becomes subrounded. By some accident of erosion the gulch plain may be disturbed and the nugget again moved, and still further reduced in size, it finds its way to the tundra deposits. By shifting of the shore line it may subsequently be exposed to wave action, ground down still smaller and eventually carried to sea as flake or flour gold and may finally be buried.

Because of the different stages of elevation of the coastal plain in former times, we should look for ancient lines of beaches in the tundra. Only along these old shore lines or in the basins of abandoned stream channels should we expect to find gold as concentrated as it is on the present beach. Topographical features are valuable in locating old buried shore line or old stream channel pay streaks without actual prospecting.

The Nome beach placers are not unique occurrences of gold, for similar deposits, though not so rich, have been known in various parts of the world, as on the coast of California and Oregon. But there in places the gold has been too fine to work. Black sand, garnets, ilmenite and small quantities of platinum are found with the gold. Such gravels might be consolidated into conglomerates or fossil beach placers yielding gold, like the ancient consolidated beach placer at the Homestake, Dakota.

Siberia across Bering strait may have a continuation of the Nome sands.

THE KLONDYKE PLACERS.

The Klondyke was discovered by a white man, half trapper, half prospector, his Indian wife and two Indian brothers-in-law, who were prospecting up the bed of a creek in the far northwest of Canada. After many unsuccessful pannings, the Indian woman made a discovery which showed several dollars to the pan; this was followed by even ounces of gold to the pan, and the Klondyke was discovered, which has since yielded £13,000,000.

About one thousand three hundred miles up the Yukon river in a country of alternate ranges of hills and watersheds, there are two tributaries, the Klondyke and Indian rivers, which fall into the Yukon about twenty miles apart. Between these small rivers the country rises to a high ridge 2,500 feet above the Yukon, and from each side of this ridge flow a number of creeks towards one or other of the rivers. The area included is about twenty miles wide by forty miles long, bounded on three sides by the Yukon, Indian and Klondyke rivers. This is known as "The Klondyke."

Over nearly the whole area of this gold field the geology consists of a very siliceous grayish green schist, often talcose or chloritic, traversed by eruptive masses of diorite and diabase in some places. The quartzose nature of the schists is marked and veins of solid quartz run through the whole mass. The creek beds, varying from fifty to a thousand feet, carry a layer of gravel from a foot or two to twenty feet thick, which in turn is covered by a layer of black bog clay. A large amount of gravel is also found in benches three or four hundred feet high on the hill slopes above the level of the creeks.

These bench or hill gravels, like those in the creeks, contain quartz boulders rich in gold. Everywhere the gold is mostly contained in the lower foot or two of the gravel, usually it has sunk into the schist itself which is decomposed for several feet in depth, and the rest of the gravel which on the hill benches is sometimes hundreds of feet thick, is almost worthless. The gold is not evenly distributed in the gravel beds. There is always a pay streak carrying more gold than the rest, which may be from fifty to three hundred feet wide.

Although there are quartz veins in the vicinity and a large conglomerate, there seems no prospective richness in either. The prospect of a quartz reef country is not at present promising.

It seems probable that the placer gold was derived from the breaking up of many small auriferous veinlets from pyritiferous diabases, and from gold-bearing rocks generally and not from any large veins in place. To get at the gold, the black mud covering the gravel has first to be removed, this allows the gravel to thaw and renders it more easily worked. There is a lack of sufficient water for hydraulic purposes.

In 1898 the overflow of prospectors from the Klondyke went to the creeks of the Atlin district in the far north of British Columbia. The so-called *gravels* at Atlin are boulders from the size of a man's head to several hundred pounds or several tons. The rocks here are a close-grained greenish magnesian slate with quartz stringers, often of a green color, from chromiferous mica, with here and there a granite boulder brought and deposited by glacial action. The gold is nuggety and exceedingly water-worn. At Atlin there is gravel of moderate value and plenty of water and fine grade for disposal of tailings. the gold-bearing creek beds lie in an area twenty miles long by eight wide. Besides deposits in the creek beds there are big benches of gravel on the hill sides to be sluiced.

The future of the Klondyke depends upon the treatment of low-grade gravels, as the high-grade pay streaks have been mostly worked out, despite the richness of the placers.

SNAKE RIVER PLACERS, IDAHO.

The gold in the Snake river, Idaho, according to Don Magnire, owes its origin to the Caribou, Snake river and Pierre-Hole mountains, the waters from which flow entirely into the South Fork of the Snake. The gold found in the sands of the South Fork at its very head differs little from that recovered five hundred miles down the stream. It is an extremely fine flour gold, so small that each infinitesimal particle will float in a moderately rapid current. It seems probable that this gold was derived from the gold values that once existed in veins of pyrite in the Caribou and Snake river mountains. Tremendous erosion and scouring away have taken place here in past ages. The glaciers and torrents of ancient times acting upon the sulphide veins of these mountains wore out the pyrite, whose particles becoming oxidized, released the tiny points of gold and sent them in countless millions down the great river to lure the miner of modern days. The gold when retorted is the rich yellow or virgin gold.

The area covered by the gold-bearing belt is very wide. Wherever we find gravel below the mouth of the South Fork there we find the gold, in some places in a measure twenty feet thick, in others in very thin measures of alternating layers from one inch to one foot apart. Wherever little eddies and bayous were formed the gold precipitated itself in the quiet waters, and as sediment formed, it found there a resting place. Wherever there is gravel there is gold, and in many cases we find it in the clay measures that form the different islands along the river. Associated with the gold is magnetic iron or black sand. The gravel is covered with about a foot of exceedingly rich black soil. When the gravel is reached a well is dug, ten to twenty feet deep to water, which flows through the gravel from the river, from a quarter of a mile to a mile away. The gold is extracted from its association with a quantity of black sand by mercury, as well as by what is known as the burlap process. The richest ground is found on shallow bars. A little bar which during one season may not afford a miner a dollar a day, worked with a rocker, may be so enriched by the rising waters of the next year as to afford five dollars per day.

The Snake river runs in a trough in amygdaloidal or basaltic rock, formed by the old volcanic tides that once rolled over these plains. The river banks are from ten to three hundred feet high, but wherever there are gravel beds or deposits of sediment, either in rifts of these cliffs or high on their surface, or still further back miles from the river, invariably we find gold upon washing the sediment or gravel. Gold is also found underneath the lava sheets.

OREGON PLACERS.

The placer deposits of Oregon, according to Lindgren, indicate the extent of the gold belt of eastern Oregon as being widely scattered over the whole area from the sands of the Snake river on the east to the gravel bars of John Day river on the west.

The placer gravels are contained in the beds of the present streams and gulches, or in bars and benches deposited by the same water courses at a former higher level, sometimes two hundred feet above the present stream bed. The depth of the gravels is about fifty feet or less. They are most abundant where intrusive diorites, granites and serpentines break through the sedimentary rocks. They are absent in the great Neocene-volcanic areas. In mountains which have been covered by glaciers during the ice epoch, placers are rarely found. The ice sheet dislodged the gravels and scattered the gold among the moraines, and since the close of the glacial epoch the time has been too short to permit a new concentration of gold. Placers are found below the terminal moraines.

Prevolcanic gravels are preserved only when covered by volcanic flows. Intervolcanic gravels were formed as follows: Volcanic outbursts flooded the lower valleys with lava. The upper valleys were thus dammed, and accumulations of gravel took place, placers formed, and gold concentrated wherever streams from gold-bearing areas entered the basin. As the cañon proceeded, benches were left at intervals and at various elevations along the present streams. Pleistocene gravels form the lowest benches and the deposits in the present channels.

As usual, the gold of the Oregon placers is largely concentrated on the bed-rock or in the gravels immediately above it. The stratum on bed-rock is the richest.

PLACER MINING IN CALIFORNIA.

Mining for gold in California commenced by placer mining which led up to vein mining. How vast the placer resources were and still are, and what a huge amount of material has been moved by the miners in days gone by, is seen as we cross the Sierras, or look down into the profound cañons of the American and other rivers that cleave the Sierras from summit to base, and see the great patches and white hummocks of abundant placer ground. Or, again, going into the more northern sections of the state, there are banks of debris hundreds of feet thick, faced

FIG. 114.—HYDRAULIC ELEVATOR, NORTH BLOOMFIELD, CALIFORNIA.

by lofty cliffs, at which the rusty monitors which did so much to reduce them now point idly, while miles upon miles of great flume and big rusty pipes tell of the energy which brought the water in enormous quantities and with mighty force from afar. We look now on an almost dead industry, compared to what it once was, yet are impressed with the idea of how great it could be again if it were revived by laws which at present arrest it

There are in California two systems of river-bearing placer material. One, the ancient dead rivers, with

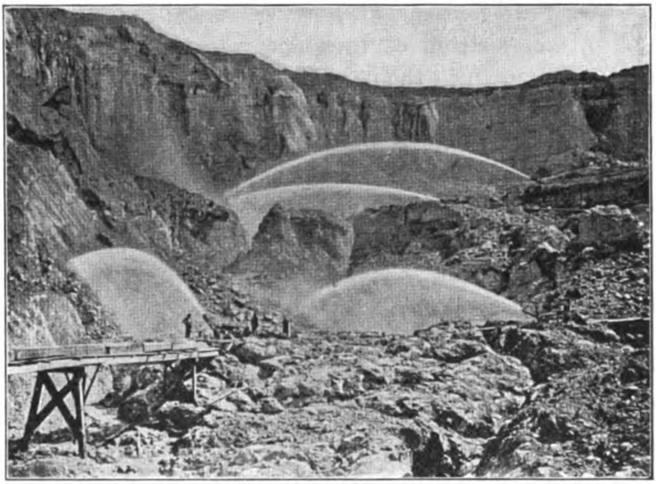

FIG. 116.—HYDRAULIC MINING BY GIANT NOZZLES, CALIFORNIA.

buried courses; the other, the present live river system. The courses of the present rivers follow very nearly those of the ancient rivers, but sometimes cross them. The size of the former varied from small tributaries a few feet in width up to the great stream whose bed lies upon the San Juan ridge, north of Nevada City, for twenty-five miles, and to a depth of gravel of five hundred feet and a width of one and a half miles, surpassing that of any living river in the state. By the effects of erosion these older channels may occupy to-day a more elevated position than the present neighboring streams. With the elevation of the Sierras, immense flows of lava issued from fissures, covering many of these river beds to a depth of hundreds of feet. So the old channels were buried, covered deep with a volcanic top dirt, and the direction of the water courses diverted.

The composition of these gravels represents nearly every rock known in the country, such as diabase, diorite, serpentine, slate, granite, syenite. In some cases the pebbles are almost wholly quartz, and occasionally of pure white quartz, as if from some gigantic quartz vein. The lowest gravels have a grayish blue tint, from iron protoxide and other causes, hence the celebrated so-called "Blue Lead" of California. Sometimes the color is due to dark volcanic ash.

In the Nevada City region the Harmony Drift gravel is an ancient river channel. The gravel is composed entirely of quartz pebbles lying on bed-rock, covered with pipe clay, sand and other gravels, and capped with lava. The quartz gravel is two feet deep, the lava cap four hundred feet. The bed-rock is a decomposed granite. Two channels exist in the upper portion, one tending east, the other northeast. The Harmony channel is two hundred feet wide. A clay mixed with the gravel is a hindrance in sluicing. In the deep channel the gravel is more cemented.

At North Bloomfield the placers are down in one of the deep cañons of the Yuba river. The banks of gravel stand in a long line of abrupt cliffs five hundred feet high, and from a distance appear almost snow white, shaded with bands of color. The top is reddish from iron oxide;

in the middle is a chalk-white band of pipe clay; the lower section is a leaden gray and rougher than the upper part, containing the coarser pebbles, presumably of volcanic origin. The lower section shows irregular splashes of gravel cross-bedded, and evidencing the action of strong currents. This terminates at the base of the cliff on upturned bedrock schist. The North Bloomfield mine is said to have been the largest hydraulic mine in the world, consisting of gold-bearing gravels resting on an ancient river channel. The pay channel is four hundred feet wide and the *blue gravel* one hundred and thirty-five feet deep. While the whole cliff from top to bottom carries a certain percentage of gold, the coarse blue gravel for about one hundred feet above bedrock is the richest. The bed of pipe clay in the middle is barren, and is a hindrance, owing to clogging the sluices.

COVERED PLACERS.

FOREST HILL PLACER MINES, CALIFORNIA.

Near Yankeeville we come upon the first signs of a high hilltop placer. It consists of ancient river drift, white clay and bowlders as a somewhat shallow deposit resting on the top of vertically uptilted slates and schists. These ancient river beds are now high on the summits of the hills, with the present river as a thin silver line two thousand feet down in the valley below.

At Forest Hill we have a good exposure of two hundred feet of gravels, showing distinctly the lenticular bodies and channels of coarse gray gravel and bowlders of granite, slate and lava, resting on bedrock schist. The gravel, as shown in the mine, consists of bowlders and pebbles firmly cemented together, so much so that the conglomerate can not be worked by a pick, but has to be blasted down like an ordinary quartz vein. The floor on which the conglomerate rests is of slate, polished and smooth. On this bedrock the most gold lies in the gravel cement. Gold is distributed through the formation from roof to floor, and is fairly coarse, like shot gold.

The main river channel is of unknown width. On the east the channel hugs the bedrock, and here within the bigger one was found a smaller and richer channel.

At Centerville is a lava-covered placer. The quartz channel, as it is called, is of white quartz, loosely cemented with quartz sand, supposed to have been derived from some great vein like the *Mother* lode. Bedrock is a black and white sericite schist or slate, standing on edge. In the tunnel, which is over a mile long, they made an upraise three hundred feet and still found gravel above them. The best gold is obtained from the foot or two above bedrock or on bedrock itself. Towards the east part of the mine, some feet below the quartz lead, is another lead known as the black lead, composed of dark volcanic rock and sand and some black slate. This channel is capped with solid lava and is the richest in gold for a height of ten feet.

PLACERS AT BRECKENRIDGE, COLORADO.

The most important placer district in Colorado is that in Summit county, near the town of Breckenridge, and along the banks of the Blue river and its tributaries. The mountains around are composed of Paleozoic limestones and quartzites, Mesozoic sandstones, shales and limestones, and here and there areas of underlying granite are exposed, together with bodies of eruptive rock.

The region abounds in ore deposits, most of which are in the nature of fissure veins, carrying pyrites and free gold, with some silver and lead. The strata are much penetrated by eruptive dikes and sheets of porphyrite. The remarkable occurrence of crystallized free gold in narrow seams and fissures in metamorphosed shales at contact with a porphyry dike on Farncombe Hill has been mentioned under the title of Summit county. As the gold in this is crystalline, when detritus from it is found in the

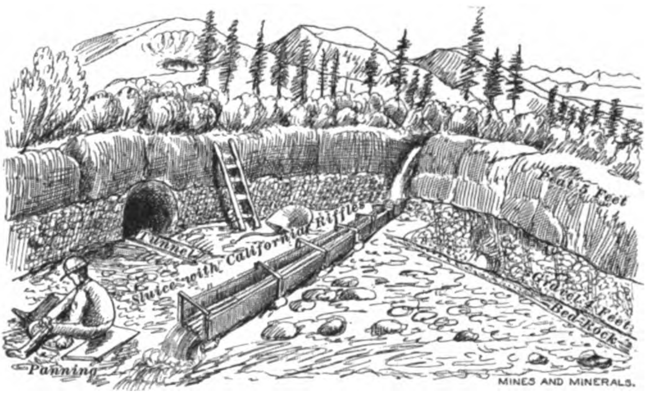

FIG. 116.—SLUICING FOR GOLD NEAR BRECKENRIDGE.

bed of the creek, the so-called placer gold is readily distinguished from the true water-worn placer gold brought from a distance by glacier or stream. The region is one of intense glaciation, and the placer deposits are largely those formed by glacial moraines, little modified by stream action. Consequently they are thick, and the pebbles and bowlders generally large.

The depth of the deposit is from fifty to a hundred feet. Gold is found all the way down from grass roots to bedrock. The bedrock is commonly shale, slate or

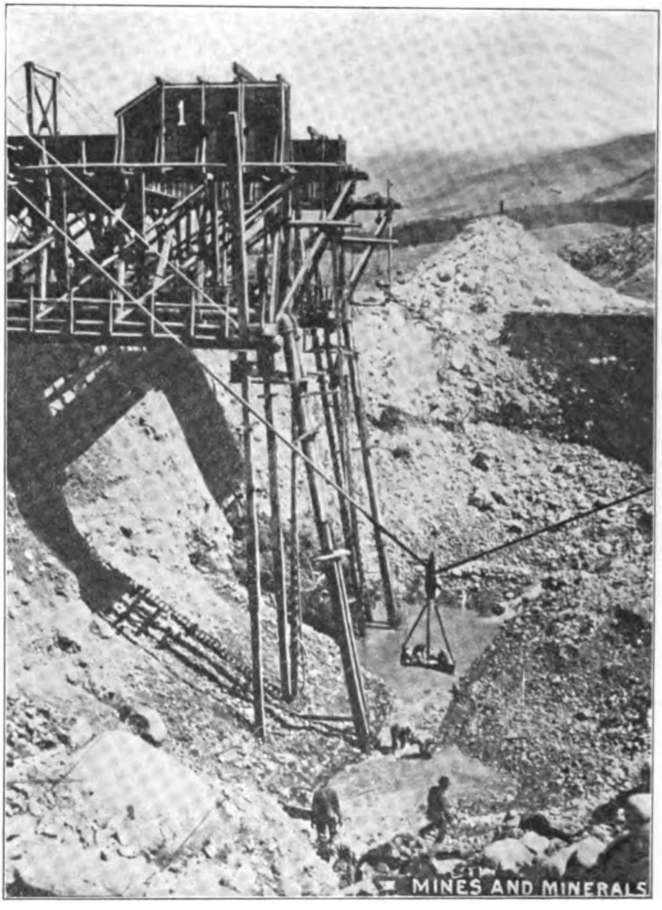

FIG. 118.—THE EVANS ELEVATOR, BRECKENRIDGE PLACERS, COLO.

granite, or one of the sedimentary formations of the surrounding hills. The deposits contain the usual sand bowlders, black sand and gold-impregnated bedrock.

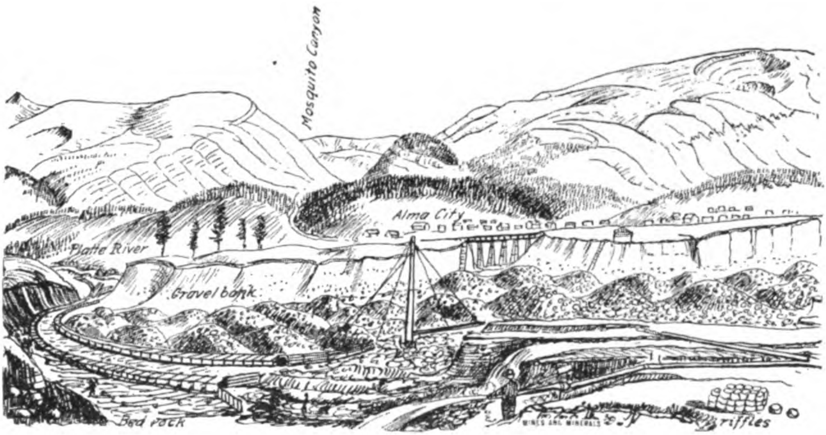

FIG. 119.—HYDRAULIC PLACER MINING, ALMA, COLORADO.

Dredging and the Evans Elevator are used on an extensive scale. Placers also have long been worked at Alma and Fairplay, South Park, also near Leadville and in the San Miguel region, Colorado. (See Fig. 103.)

DRY PLACERS.

(By G. H. Stone.)

There are numerous dry placers in many of the arid regions such as Arizona and New Mexico. These placers were formed by ancient and now extinct rivers, or by sudden freshets and other erosive agencies. In these gold is frequently present, but from the absence of water in the vicinity it can only be recovered, if at all, by some so-called dry *washing* process, few of which have hitherto proved commercially successful.

The more common dry plàcers consist of gold in the ruins of sedimentary rocks. In the region of the Plains, the Rockies and the Great Basin we find many places whence deep bodies of sandstones and conglomerates have been eroded. These rocks, like all assorted sediments, contain more or less transported gold. We sometimes find the gold, or the pay streak, at or near true bedrock, but more often at various levels above true bedrock, resting on layers of cement that form false bottoms. Most of these dry placers were deposited by intermittent rather than by constant streams. The gold came down during the more violent floods, such as cloud bursts. In this dry region there is not one but many false bedrocks. One may be near grass roots, another a little lower, and so on. Shallow grass-root concentrations can be found wherever sandstones and conglomerates have been eroded. Bedrock in these regions is where you find it. These dry placers are often known as high bench placers.

GENERAL REMARKS ON PLACERS.

(By Edmund B. Kirby.)

The distribution of gold is irregular and uncertain to an extreme. Only small portions of a placer at best can be rich enough to pay. Local enrichments are due to the concentrating action of the stream at intervals during its history. They are therefore subject to all the irregularities which might be expected from the ceaseless shifting and changes in the material deposited.

In most cases presented throughout the West, the gold-bearing gravels are deposited from the present system of streams, and their form and position have been developed probably during the Quaternary period.

The high gravels of the California ancient rivers are of earlier date, and form a class by themselves. As compared with the more recent deposits, they are limited in quantity and differ radically in structure, character of the gravel, grades and method of working.

The first mentioned deposits may be conveniently classed as high bars (above water level), and bottom gravel (at and below water level). The high bars are remnants of beds which were deposited before the stream cut down its gulch or valley to the present depth. They were originally terraced, but have frequently been shifted or changed in external shape by erosion. They were the most accessible and easily worked deposits, and are now very scarce.

The deep gravel filling the present gulch or valley bottoms below water level constitutes the principal bulk of the deposits now remaining in every placer district.

It is clear that the climatic and other conditions under which a stream cut down its channels in the bedrock were different from those which prevailed while gravel beds were deposited in the channel. In the first case, there was a large volume of water and probably steep grade. In the second case, both water flow and grade were less, and this is the condition which now prevails in our western streams and rivers. The present grades are generally less than two per cent., and the transporting action on large gravel, even in time of freshet, has almost ceased. The bedrock is now protected from erosion by a more or less heavy bed of gravel, over the surface of which the stream flows. In many cases the processes of erosion and deposition have alternated frequently, and this accords with what is known of climatic changes during the Quaternary period.

The gravel beds are made up of various streaks or layers, some of which may be gold-bearing, while others are entirely barren. These layers have all the irregularities of stream-deposited gravel. They are sometimes quite uniform in thickness and value, over considerable areas, as though spread out by floods. In other cases, they form crescent like overlapping streaks, varying greatly in gold contents, and indicating their deposition in side bars by the stream as it shifted its position.

During the deposition of gold-bearing gravel, the light or scale gold is apt to be distributed very uniformly throughout the entire mass. The heavy gold, on the other hand, tends to concentrate out in special layers or streaks. It is a frequent occurrence to find rich layers on top of barren layers; and many facts indicate that during the deposition of rich gravel, its gold contents do not work down through undisturbed gravel beneath. When pay gravel exists in the gulch it is usually confined to a ribbon-like layer on or near the bedrock. It is not likely that this is the gold that has sifted down from the overlying mass. On the contrary, the bedrock channel acted for a long time like a sluice. As the transporting power of the stream gradually lessened, its gravel was alternately moved and re-deposited. This sluice action, with the repeated shifting and loosening of the first deposits, doubtless caused the gold to accumulate in the bottom layers.

This pay lead or bedrock channel is usually of limited width, and meanders along the gulch, marking in general the course and width of the stream at the time. There may be two or more of these channels, and they are not necessarily in the deepest part of the gulch. They may be found higher up along its sides, as portions of earlier channels made before the bedrock of the gulch was cut down to its present depth. In such a channel the distribution of gold is very irregular, but on the whole it seems to follow the rule so often observed, and is heaviest on the inner sides of bends.

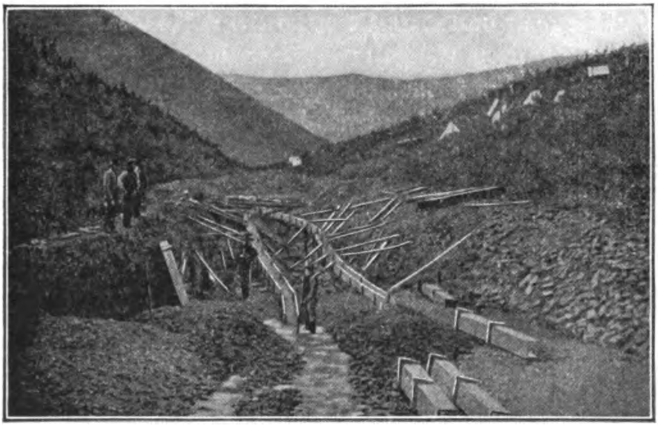

FIG. 120.—SLUICE MINING.

It is usually necessary to work the channel by a pit or open cut. It is a rare occurrence to find that the general mass of gravel filling the gulch will average enough to pay. (Fig. 120.)

CHAPTER XII.

The following brief accounts of some of the most important mining districts of Colorado and other Western States are in no sense official reports of those districts or of the individual mines mentioned, but simply examples illustrating the principles of the preceding chapters:

BOULDER COUNTY, COLORADO.

Along the foothills adjoining the plains is a series of *hogbacked* ridges, formed by the upturned floor of the prairie, consisting of Triassic, Jurassic and Cretaceous strata, resting on the Archæan granite core of the range. These upturned sedimentary beds of sandstone, limestone, clay and shale form a fringing belt, varying in width and dip, along the entire extent of the eastern foothills. South of Boulder their dip is almost vertical, forming near South Boulder Cañon a magnificent peak, 3,000 feet above the plains.

The Upper Cretaceous or Laramie Group contains valuable coal beds, whose outcrops, owing to erosion, are at Boulder some miles out on the plains. The *hogbacks* supply excellent building stone, flagstones, fire clay and lime; they are barren, however, of precious metals, both here and generally along the eastern foothills.

The Archæan granite rocks immediately adjoining the plains have also, as a rule, been found to contain but few valuable minerals. A few copper stains and some local deposits of copper are nearly all that are found. It is not until the range has been penetrated for a distance of several miles that productive deposits appear.

The Archæan rocks consist principally of a granite-gneiss, showing indistinct signs of primitive bedding. This is intersected by veins of pegmatite, or very coarse, crystalline and sparry granite, varying in width from a few inches to fifty or more feet. Two of these veins, the Maxwell and the Hoosier, are strong and well defined, traversing the district for several miles. The Maxwell strikes east of north, crosses the road two miles from Boulder on the way to Sunshine, and is conspicuous from its reddish-white and rusty color. It carries pyrites and tellurides. The Hoosier vein, or rather gangue, forms the western limit of the telluride belt, and runs through Gold Hill in a direction east of north. It carries silver ore and gray copper. The Telluride belt underlies the Magnolia, Sugar Loaf, Gold Hill and Central districts. Eruptive rocks are scarce, but pegmatite veins abound in this belt. West of this region enormous masses of eruptive rock occur, but tellurides are not found.

In the Caribou district are rich silver ores, carrying up to 1,500 ounces of silver to the ton. In the Ward district veins carry free gold, with iron and copper pyrites. The general direction of these veins is east and west, while the others are more nearly north and south. Of eruptive rocks, that which forms the Sugar Loaf is a fine-grained porphyrite, of a grayish-black color, showing small white feldspar, black mica and hornblende, crystals of titanic iron, and a little augite. The crystalline ground mass, in which these crystals are set, consists principally of feldspar, with a little quartz. A similar rock, showing large feldspar crystals, is on Four Mile Creek. It is a massive eruption of considerable extent. East of the Sugar Loaf is a dike of dense black diabase, not unlike basalt. At Jimtown a light colored quartz diorite dike, containing much hornblende and titanic iron occurs and runs nearly through the street of the village. The adjacent cliffs, over five hundred feet high, are a white quartz porphyry, consisting mainly of large crystals of quartz and feldspar set in a fine-grained crystalline ground mass.

The mines of Boulder County are on the eastern slope of the Colorado range and begin not more than two miles from the plains. The mining district is about thirteen miles long by from four to ten wide, exclusive of Caribou Hill. The district contains very rich ores, and is celebrated for the occurrence of telluride minerals.

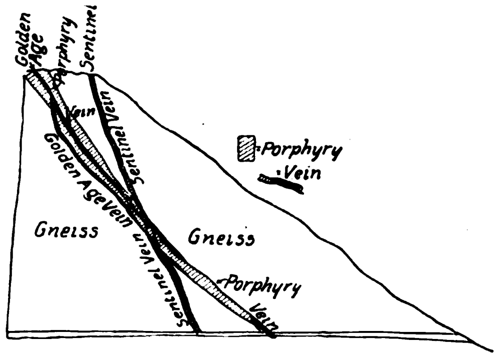

FIG. 121.—CROSSING OF VEINS, JIMTOWN, COLORADO.

The Golden Age Mine, near Jimtown, in the Central district, is on two cross veins at contact of porphyry and granite. The veins are in places forty feet wide. The principal ore comes from a streak of white quartz, one or two feet thick, sometimes very rich in free gold. A narrow cross vein occurs carrying only tellurides. Pyrites also occur. Rich concentrations of ore are found at intervals.

Gold Hill district is in the telluride belt traversed by the Hoosier gangue. Several of the veins cross the

Hoosier, and are richer in its vicinity. The vein of the Red Cloud is three and one-half feet wide. The ore was telluride at the surface, passing into auriferous pyrites with depth.

Sunshine is also in the telluride belt. Its ores are lower grade. Free gold and tellurides occur on the surface, passing into pyrites with depth.

Sugar Loaf, also in the telluride belt, is an enrichment of the Hoosier gangue, the gangue being pegmatite.

In the Keystone mine of the Magnolia district, is a narrow deposit, six or seven inches wide, yielding a telluride ore.

The Ward district is outside of the telluride belt. The ores here are copper and iron pyrites bearing gold.

The Caribou mine has yielded a great deal of silver. Its ores are a mixture of galena, chalcopyrite and zincblende, occurring in a vein in gneiss near a dike of eruptive diabase.

The No-Name crosses and faults the Caribou. The ores are silver glance, stephanite, gray copper, argentiferous galena and copper pyrites. Native silver is common, also some ruby silver. The copper pyrites carry more gold than silver.

As a rule the veins in Boulder county are not of great extent. A single vein can rarely be traced on the surface or beneath it for more than six hundred feet. Before that distance is reached the vein usually spurs off into another vein, follows it for a while and spurs off again into another. There are two general courses of veins, one east and west and the other northeast by southwest. The veins, that is the *pegmatite* gangues, are called *true fissures,* and are often very wide. But, if the term "true fissure" means, as Mr. Emmons says, "a vein which occupies a deep-seated, wide gaping fissure, filled in by vein matter and ore, coming from unknown depths, and distinct and foreign to the material of the adjacent rock, there are no such true fissure veins in this district," and we may go further and add, nor in Colorado generally.

The late Professor Van Diest considered that the granite rocks near Boulder were thrown into a series of parallel folds; first, a great fold following the Continental Divide, prominent near Gold Hill; another near North St. Vrain, and a third between Middle and South Boulder; also two prominent side folds, cutting these diagonally and running, the one from Ballarat to Jimtown, the other from Sugar Loaf to Gold Hill. Along the slopes of these folds are the telluride veins. He associated the veins with cracks and fissures coinciding with the folding. Some of the main fissures were filled at once by porphyry dikes, the others more gradually by vein material. He attributed the veins to percolating alkaline waters dissolving metalliferous material and veinstone from the surrounding rocks, and observed that alkaline springs still exist in the neighborhood, as in the mining district of Idaho Springs. The veins occur where the foldings are abrupt, and their direction is parallel to the strike of the stratification, while their dips are very steep or nearly vertical.

The gangue or vein material is simply an alteration of the adjacent granite or gneissic rock, as shown by its composition, which is quartz, feldspar and some mica. This is impregnated with rich mineral, whose source we venture to say is not far to find. The impregnation has taken place either along the contact of an eruptive porphyry rock with the granite, or else in a pre-existing vein of pegmatite, or along some fault or jointing plane in the country rock itself, which has been favorable to the concentration and precipitation of metalliferous minerals from their solutions. This account will fit many of the so-called *true-fissure* veins of Colorado.

The ore occurs in "chimneys or pockets," with a good deal of nearly barren ground between. Small veins run parallel with each other for some distance, the interval filled with granite or pegmatite. The ore streak is from one to twenty inches wide, and contains more horn-quartz than the country rock. Some of the veins interlace like arteries in a body. Where veins cross at a small angle, or when a spur branches off from the main vein, accumulation and enrichment of ore takes place. Minute particles of pyrites often produce a dark stain in the telluride quartz. By moistening the stone the telluride minerals and the pyrites appear distinctly.

ORE DEPOSITS OF JAMESTOWN.

Jamestown, or Jimtown, mining camp lies a little north of Boulder. Its ores are largely gold-bearing. Mr. John B. Farrish has given an interesting account of two typical veins, called the Golden Age and the Sentinel, from which the following is taken:

"The Golden Age location covers the outcrop of a quartz-porphyry dike which cuts through the granite with a strike of north, 70° east. This dike varies in width from a few feet to about fifty, and dips south with an angle of 45°. The outcrop of the main ore chute on the Golden Age is marked by a line of surface works extending along the contact on the lower side of the porphyry dike from the line shafts on the east to the main shaft on the west. (See Fig. 121.)

At a depth of about 100 feet the main shaft discloses a split in the vein. The upper or hanging wall streak, called *the hanging wall vein,* continues into the dike on about the same dip, but with porphyry hanging and foot walls, until a depth of 330 feet is reached, when it enters the upper contact between the porphyry and granite, and remains in it to the bottom of the main shaft, 470 feet on the incline below the apex. The adit tunnel cuts the porphyry dike about 250 feet below the bottom of the shaft, and shows this streak in the same contact. Below the split the lower, or foot-wall streak, called *the foot-wall vein,* stands a little straighter, and at the second level, 180 feet below the surface, is found on the contact between the underside of the porphyry dike and the granite foot-wall. It remains on this contact generally, though occasionally found only on the granite, down to the bottom of the shaft.

The porphyry dike varies both in width and dip. On the third level it is 47 feet wide, and in the adit only 8 feet. It has been much acted upon by vein forming agencies, mineral solutions, etc., on the upper workings, and is much decomposed. In the adit it is more compact and unaltered and shows considerable pyrites.

The Golden Age veins are well defined, presenting a typical banded or ribbon structure. They are enclosed in distinct walls with gouge and slickensides. The seams and feeders that radiate from the veins come in from the porphyry dike. The ore is remarkable for very rich specimens of free gold. It is on the upper levels a typical free milling ore, a good percentage is saved by amalgamation on copper plates, the resulting bullion being over 900 fine, and the tailings yield iron-concentrates of fair grade. As a rule it is a hard, flinty or vitreous-appearing white quartz. The gold, especially in the hanging wall vein, is seldom accompanied by pyrite, or any of the baser minerals. It is generally imbedded in the white quartz, as bright yellow gold, in size from coarse grains to nuggets of several ounces in weight. One specimen contained seventy ounces of gold in one piece. The foot-wall vein contains more of the base metals than the hanging wall, and there is a marked increase in the quantity after it reaches the lower contact between the porphyry and granite, and a still further increase when it leaves the contact and enters the granite. In such places blende and galena appear in small quantities, with pyrite and copper pyrites, but the ore retains its value in free gold. In none of the openings were any tellurium minerals found, nor do they occur in the Golden Age veins.

The Sentinel mine location covers the apex of a vein enclosed in a belt of schistose or gneissic rock. It lies nearly parallel to and about 100 feet south of the apex of the Golden Age veins. In driving the adit tunnel the first vein encountered was the Golden Age on the hanging wall contact of the dike, and about 175 feet further north the Sentinel vein was reached in granite. An upraise on this vein from the main shaft demonstrated that the vein dips at an angle of 70°, passing through the Golden Age vein on its course.

The ore of the Sentinel vein is entirely distinct from that of the Golden Age. It is the characteristic bluish horn quartz of the tellurium veins of Boulder county, with the distinguishing chalcedony, quartz crystals and finely disseminated pyrites. The value is in metallic gold, petzite and sylvanite. The ore is very rich. One specimen found weighing two pounds was valued at $228; and shipments of first-class ore have been made to the smelters returning from ten to seventeen dollars per pound. It is the practice in handling this high grade tellurium ore to amalgamate as much as possible in a mortar by hand, and ship the remaining tailings. As illustrating this, I will cite one lot selected at random of 17⅜ pounds, which yielded $200.00 in bullion, and then netted at the smelters $80.60, the assay on the tailings being 435 ounces gold and 84 ounces silver to the ton.

The richest ore occurs in two seams or narrow streaks, often from a foot to, at times, as much as ten feet apart, the intervening space being more or less mineralized country rock. The miners leasing on this vein consider it richest when it is in the schistose rock, and poorest where it is in the porphyry on its course through the dike.

So distinct are the characteristics of these veins that the crossing of the Sentinel through the Golden Age is plainly marked, being exposed on the main shaft and workings connected with it. The dip of the former, as stated, is about 70° to the southward, and is regular, though at the points where it comes in contact with the quartz streaks of the Golden Age veins it often follows along, without a break in its continuity, either above or below them for short distances before finally passing through and assuming its regular dip. Nor does the dip of the Golden Age vein appear to be much disturbed, the greatest vertical displacement noticed, being about thirty inches at a point where it is broken by the passage through it of the Sentinel veins.

The facts observed appear to confirm the opinion that the gold mines of Boulder county belong to at least two distinct periods of vein formation. To a first, or earlier, can be assigned the Golden Age, the mines of Ward, and other districts producing similar ores from telluride minerals; to a second, or later, the telluride gold veins for which the county is particularly noted. That the ores from the Sentinel telluride veins are lower grade where the vein passes through the porphyry dike than elsewhere is probably due to the prior formation of the Golden Age vein. This has drained the dike of its disseminated mineral values. The Sentinel doubtless received its metal from the schistose or gneissic rocks, and is consequently richer where enclosed in those rocks than when in the dike.

Prospectors look for richer or larger bodies of ore where veins unite or cross. In this property we have two interesting occurrences of this kind. The two Golden Age veins unite at a point one hundred feet below the surface. These are similar veins of the same age. The result was the large and rich ore bodies mined in the stopes near the main shaft in the upper portion of the mine and adjacent to the junction of the veins. The other case—the crossing of the Sentinel telluride veins through the Golden Age veins—produced no local enlargement or enrichment of the ore bodies. It is evident that to form such ore bodies, except in rare cases, the veins should be of contemporaneous origin.

Boulder county produced in 1903 as follows: Gold, $431,568; silver, $33,049; lead, $4,876; copper, $814; total, $470,307.

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CHAPTER XIII.

GILPIN COUNTY, COLORADO.

The geology is similar to that of Boulder County. The region consists of Archæan granite and granite gneiss, penetrated by felsite and quartz porphyry dikes. The region is one characterized by much folding, fracturing and fissuring of the rocks, accompanied by volcanic intrusions, a geological condition eminently favorable to ore occurrence. A notable feature of the area is the immense number and large size of pegmatite veins by which it is traversed.

Here, also, the veins are only alterations of the country rock along certain planes, and do not occupy a once wide gaping fissure. The vein of the Minnie mine is a felsite porphyry; that of the Cyclops mine, a quartz porphyry. Dikes of porphyry occur near the lodes or in contact with them. The veins have been traced for 3,000 feet or more in length and to a depth of over 2,000 feet. The direction of the veins is north northeast and south southwest, and nearly east and west. The dip is nearly vertical. The veins follow the cleavage planes of the country rock. These cut the stratification planes at right angles, with a vertical dip. It is presumed that the porphyry dikes are older than the veins, as the cleavage intersects the porphyry equally with the other strata.

The ores are a mixture of iron and copper pyrites, with very little galena and some zinc blende. All carry more or less gold. The diameter of the gold district, which is very distinct, is about one and a half miles. In the gold veins the richer ore occurs in streaks not over a foot wide, in a fine grained, compact mass of pyrites. The copper pyrites carry more gold than the ordinary iron pyrites. The rest of the vein, often many feet wide, carries pyrite irregularly disseminated through decomposed country rock. These ores are for the most part difficult to treat and are milled, the loss being 40% higher in the unoxidized than in those completely oxidized.

Mr. Forbes Rickard has given an excellent account of this county, from which the following is chiefly taken:

"Gilpin county is the oldest mining camp in Colorado, and has produced in the past forty years upwards of $100,000,000 in gold and silver. The veins of this, as well as Clear Creek county, occur in Archæan gneisses and schists, associated with dike-like masses of pegmatite, and with porphyritic andesite dikes. The fissure veins sometimes occupy a line of faulting, but the displacement is seldom great. Usually there is one well-defined wall, rarely two. One wall is frequently much broken. The filling is often scarcely distinguishable from the material of the vein walls.

The district contains a gold belt and a silver belt, which are fairly distinct, though they merge gradually into each other on the confines. The silver belt occupies the eastern limit of the region about the town of Black Hawk and immediately east of North Clear Creek. The average proportion of silver to gold throughout the country is about five ounces of silver to one of gold. The ores of the silver belt are remarkable for the absence of gold, while in the gold belt both minerals are represented in the general ratio of five to one.

There are two distinct sets of veins, one about east and west and the other northeast and southwest, with an infinity of minor parallel, diagonal and cross veins. Intrusive andesite dikes occupy both main lines, occurring in conjunction with mineral veins, upon whose ore deposits they apparently have considerable influence. They often form a wall to the vein, and when that is the case the divergence of the vein from the dike usually coincides with an impoverishment. The veins have shown good continuity in depth. The California mine, 2,250 feet deep, still shows good ore at the bottom. Many lodes that yielded well at the surface have yielded well with depth, and the opposite is also true. The lodes show oxidation to a depth varying from forty to, in some cases, two hundred feet. Below the oxidized zone depth brings no perceptible change of value to the ore or to the character of the bullion recovered in mill or furnace. When at a comparatively shallow depth some veins have pinched, or the grade of the ore has fallen off, the miners use the word *Cap.* Some veins are simply poorer than others, and a *cap* will not disguise the fact. The properties of the veins are often influenced by the strike or dip, a change in direction of these being not infrequently accompanied by enrichment or impoverishment. A steeper dip often coincides with a change in the vein for the poorer. The junction of veins results frequently in a local enrichment. Converging veins do not always cut one another, but after running closely parallel for a distance diverge again. Sometimes a vein will ramify with a dike so as to scatter all through the porphyry mass, and when the vein is rich it may give to the whole an economic value. Such a condition exists in Quartz Hill, where an area known as the "*patch*" is impregnated and seamed with ore to such an extent as to give the whole mass an appreciable value in gold and silver. The mass is penetrated by an andesite dike. The main body is pegmatite, consisting of a crystallized mixture of quartz and feldspar, with little or no mica. The feldspar is partly kaolinized and the rock contains much drusy quartz, pyrite, zincblende. Siderite and galena are disseminated through it. The *"patch"* is altered gneiss granite country, where the agency of percolating waters was very effective in promoting its decomposition and alteration.

Large rounded *bowlders* occur in the San Juan mine, and in some others, several hundred feet from the surface. These so-called *bowlders* result from the solvent action of percolating waters in the vein filling, and in some cases may have been in part produced by attrition in the process of faulting of the vein fissure.

The Ores. The common type of lode filling or smelting ore is an iron streak, and a larger width of milling ore. It sometimes carries on either hanging or footwall a selvage or gouge clay seam, and at other times is without much parting.

The smelting ore is the more compact ore of iron and copper pyrites; the milling ore of felspathic matter, and some quartz, impregnated and seamed with the same sulphides. The relative average proportion is about five tons of smelting to every hundred tons of milling ore.

Pyrite, associated with chalcopyrite, zincblende, gray copper and rarely enargite. is the principal carrier of gold. Tellurides have been detected in some of the mines; bismuth and arsenic are associated with some of the ores; and uraninite or pitchblende is found in considerable quantity in the Wood Mine. In the silver belt, polybasite, stephanite and horn-silver are found, though the common ores are galena, zincblende and pyrite. Fine specimens of gold have been taken from the Gilpin mines, such as gold incrustations on pyrite in leaf form, in crystalline form as octahedra, and as a pseudomorph after pyrite. The gold appears otherwise altogether in mechanical association with the sulphides of the ore. In parts of the mining area the ores of iron, copper, anti-

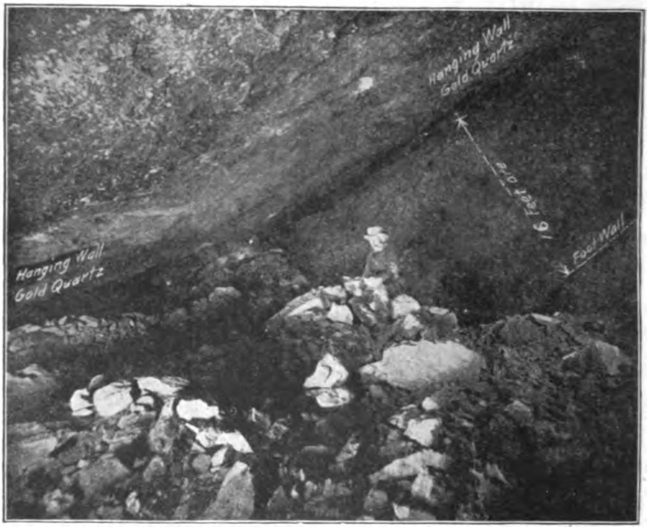


FIG. 122.—GOLD QUARTZ VEIN, TOPEKA MINE, CENTRAL CITY, COLORADO.

mony and zinc predominate over other metallic sulphides. The copper pyrites carries most of the gold; the lead, zinc and antimonial sulphides in the same vein carry the silver contents. Iron pyrites assays close to the average value of the whole ore. Coarsely crystalline pyrite is usually of low grade.

In the country rock enclosing these veins, titaniferous iron, epidote, magnetite, garnet, tourmaline and graphite are of common occurrence.

There are two or three features of peculiar interest in both Gilpin and Clear Creek Counties illustrated by the mines. One is that a gold lode was first discovered in Colorado in the Gregory mine of Gilpin County in 1859. Another, that there is no geological difference between the gold veins and the silver veins in this region. Third, that the continuity of the veins downward has been proved by the depth of the mines, especially by the

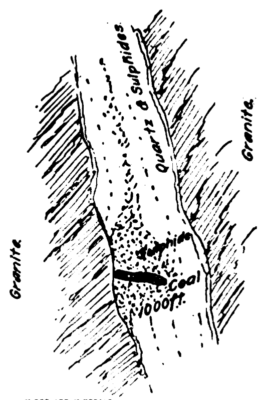


FIG. 123.—CARBONIZED STUMP IN FISSURE VEIN.

California, which has attained a depth of 2,250 feet, and by the Newhouse tunnel, which intersects the Gem vein at a depth of 2,000 feet, where the vein is found to be larger and stronger than at the surface. Nowhere else in Colorado is the downward continuity of veins so well exemplified and proven.

The output of Gilpin County for 1903 was: Gold, $1,346,113; silver, $200,564; lead, $10,080; copper, $80,996; total, $1,667,753.

Of Clear Creek County for 1903 the output was: Gold, $472,061; silver, $455,224; lead, $146,254; copper, $38,365; zinc, $35,424; total, $1,147,328.

A peculiar natural phenomenon occurs in one of the mines of this district in the form of a carbonized trunk of a tree, at a depth of 1,000 feet from the surface, enveloped in the quartz and ore matter of a true fissure vein.

CHAPTER XIV.

SUMMIT COUNTY, COLORADO.

The high mountain portion of this county consists of Archæan granite rocks. Along the valley of the Blue River, fragmentary beds of the Silurian, Carboniferous, Jura-trias and Cretaceous, which have escaped erosion, occur as relics of a former connection of the seas which filled the South and Middle Parks. These rest on the Archæan granite of the Park Range, and are repeated on its west side. Along the upper portion of the Eagle River, now in Eagle County, Silurian and Carboniferous beds appear, dipping north and resting on the Archæan granite of the end of the Sawatch Range. Associated with these are many eruptive porphyries, showing as usual a marked connection with the relative richness and size of the ore deposits which occur all the way from the Archæan to the Triassic. At the head of the Blue River, the Silurian, Carboniferous and Triassic formations have been much traversed by eruptive sheets, with consequent metamorphism of the sedimentary beds. These beds are much faulted, and the principal developments center around Breckenridge.

The Helena Mine, in French Gulch, has an ore of free gold, with some silver, as an impregnation of quartzite, for forty-five feet in width. The quartzite is rusty by the leaching out of the original auriferous pyrites. In the McKay Mine, argentiferous galena and carbonates of lead occur near an overlying bed of porphyry in a sedimentary rock. The Monte Christo Mine, on Quandary Mountain, has a deposit of low-grade galena, and zincblende impregnating Silurian quartzite.

In Ten-Mile district the ores are mainly in the Upper-Carboniferous limestones and sandstones. This is an area of great eruptive activity, and abounds in intrusive sheets and dikes of porphyry. The ores, consisting chiefly of pyrites with zincblende, are rather low grade and refractory. Most of the ore bodies occur in thin beds of limestone at their contact with sandstone, more rarely at contact with a bed of porphyry, or impregnating a porphyry dike. The Robinson is the principal mine of this district. Its ore is a high-grade argentiferous galena, associated with pyrites and zincblende, and occurs near the surface of a bed of gray limestone, dipping north 17 degrees. The ore is a replacement of the limestone. Below this the ore is galena and pyrites, extending to various depths in the limestone, and in the larger bodies occupying its whole thickness. The greatest width of the ore chute is two hundred feet, it has been traced three thousand feet following the dip. A fault plane follows the line of the ore body, and probably furnished the channel through which the ore solutions reached the limestone, as pyrites extend all through the fissure.

On Elk Mountain ore is found in a thin bed of limestone at a higher horizon still than that of the Robinson. It even extends up into the Triassic red sanstone, but is poor in silver. The Pride-of-the-West, on Jacques Mountain, is a dike of porphyry impregnated with barite and ore.

It is interesting to note that the ores of this district occurring in the limestones and sandstones are in a higher geological horizon than at Leadville.

A somewhat peculiar feature of the ore deposits in the vicinity of Breckenridge, along the banks of the Blue River, is that many of them occur in vertical fissures, traversing the eruptives as well as the Carboniferous and Mesozoic sedimentaries below, and may extend down into the granite bedrock. They carry silver, lead and gold. Other deposits occur in much-faulted blanket veins.

A remarkable occurrence of gold is in Farncombe Hill, near the head of French Gulch. The hill consists of shales, traversed by a wide dike of quartz porphyry. This dike is more or less impregnated with gold, but the finest crystallized gold occurs in veins or veinlets in a series of minute cracks or cleavage planes, one set cutting the shales from northeast to southwest, the other from southeast to northwest. Rich pockets are met where the two series intersect. The fine seams contain a talcose substance rich in gold and associated with calcite. Sometimes the walls of these fissures for several feet are frescoed with crystalline gold in fine wires and broad flakes. Lead sometimes occurs entwined with gold wire. Copper and pyrites are also present in some veins. The gold is carefully scraped from the walls of shale. Occasionally rich bodies of ore are found in the porphyry dike, which is evidently connected with their origin. The gold was either in solution or in a vaporized or sublimated condition when it ascended through these minute lenses of least resistance, and was precipitated and crystallized upon the walls of the fissures. It seems probable that the porphyry eruptive supplied both the gold and the sublimated vapors. In the placer in French Gulch, below the mine, it is easy to distinguish the gold that came from

Farncombe Hill by its little wires and crystalline condition.

Summit County is credited for 1903 with the following production: Gold, $222,264; silver, $117,880; lead, $64,559; copper, $5,485; zinc, $29,743; total, $439,931.

CHAPTER XV.

PARK AND LAKE COUNTIES, COLORADO.

A study of the Mosquito range is essential to an understanding of the Leadville ore deposits, which occur on its western side. It has a length of nineteen miles, and including its foothills, bordering the Arkansas Valley on the west, and South Park on the east, a width of about sixteen miles, its base being at an elevation of about 10,000 feet above sea level. There is a sharp, single crest trending north and south. To the west this crest presents abrupt cliffs, descending precipitously into great glacial amphitheatres at the head of the streams flowing from the range. This abrupt western slope is due to a great fault extending along the foot, by which the continuation of the sedimentary beds, which slope up the eastern spurs and cap the crest, are found at a very much lower elevation on the western spurs. The jagged, step-like outline of these western spurs is due to a series of minor parallel faults and folds.

Mounts Bross, Cameron and Lincoln constitute an independent uplift, and the secondary uplift of Sheep Mountain, on the eastern slope, is due to a second great fold and fault.

The range has been sculptured by glaciers into cañons, and the Arkansas Valley is covered with horizontal terraces, representing the distribution of detritus by waters.

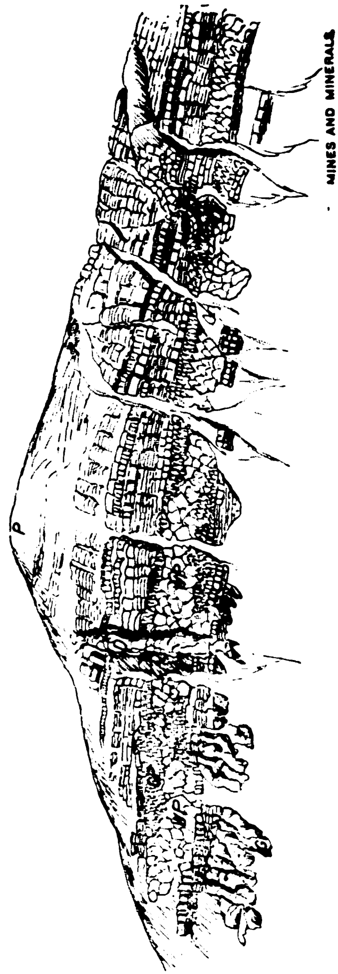


FIG. 124.—NATURAL SECTION OF PART OF MOUNT LINCOLN, SOUTH PARK, COLO.

In the Paleozoic and Mesozoic seas, which surrounded the Sawatch islands (Figs. 126, 127, 128) some ten thousand feet of sandstone, conglomerates, dolomitic limestones and shales were deposited, Towards the close

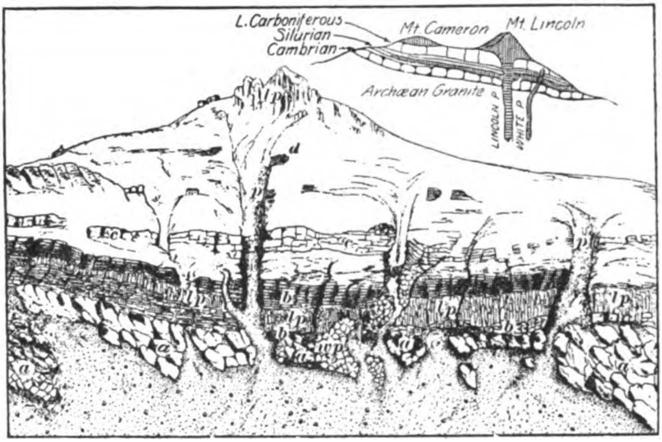


FIG. 125.—STRUCTURE OF MOUNT LINCOLN, COLORADO.

of the Cretaceous eruptions occurred, by which great masses of eruptive rocks were intruded through the Archæan floor into the overlying sedimentary beds, and, crossing some of these, spread out in immense sheets along the planes of division between the different strata. So great was the intrusive force that comparatively thin sheets of molten rock were driven continuously between the sedimentary beds for distances of many miles. The eruptions were intermittent and continued for a long time, but preceded the great movement at the close of the Cretaceous, which uplifted the Mosquito and other Rocky Mountain ranges.

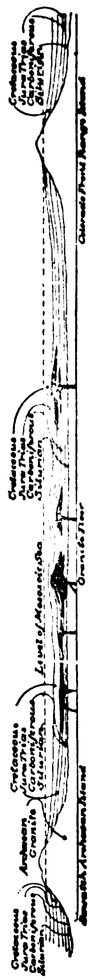


FIG. 126.—EARLY CONDITION OF THE PARK REGION BEFORE FOLDING.

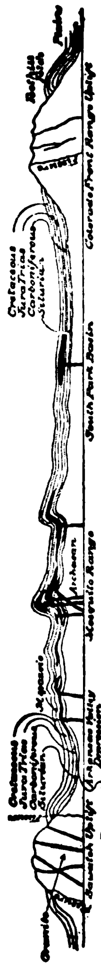


FIG. 127.—FOLDING OF STRATA OF SOUTH PARK REGION BEFORE EROSION AND FAULTING TOOK PLACE.

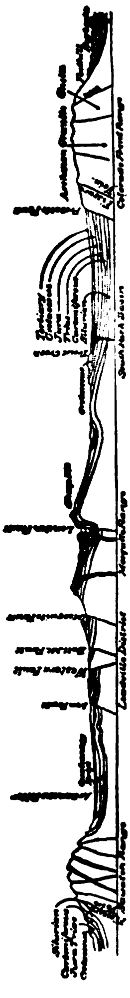


FIG. 128.—GEOLOGICAL SECTION OF THE SOUTH PARK RANGE AS IT IS TO-DAY.

Between the close of the Cretaceous period and the deposition of the Tertiary strata, the pent-up forces of contraction in the earth's crust, which had long been accumulating, found expression in dynamic movements, pushing together from the east and the west the more recent stratified rocks against the relatively rigid Archæan land masses, and thus folding and crumpling the beds in the vicinity of the shore lines of the gradually receding ocean. In this movement, also, the crystalline and already contorted beds of the Archæan doubtless received fresh crumples. A minor force acted similarly north and south, producing gentle lateral folds along the foothills, at right angles to the general trend of the range. These movements were not paroxysmal or sudden and violent, but gradual and protracted for an enormous lapse of time, and appear to be continued in diminished force up to the present day.

The uplift of the Mosquito range consisted of a series of anticlinal and synclinal folds, fractured by faults. The crest is formed by the great Mosquito fault, running north and south along the trend and axis of the range. The other great fracture is the London-Mine fault, running in a southeasterly direction along the eastern spurs of the range, coinciding with a magnificent anticlinal fold seen on Sheep Mountain and in Sacramento Gulch. On the western side the folds, faults and cross-faults are more numerous, breaking the country up into a series of blocks and steps. The movement of these faults has been an upthrow to the east. The greatest movement is towards the center or Leadville region, and dies out at either end north and south. The aggregate displacement in the region of greatest movement is from 8,000 to 10,000 feet.

FIG. 129.—FOLDED AND FAULTED STRUCTURE OF MOSQUITO RANGE

The crests of the folds and whatever cliffs may have been caused originally by the displacement have been planed down for the most part by erosion. The effects of the erosive forces are best seen in the Arkansas Valley, which was occupied for over a hundred miles by a grand *mer de glace,* fed by numerous side glaciers from the adjacent ranges. There appear to have been two glacial epochs in this region, followed severally by eras of warmer weather. The moraines were deposited by the ice. By the melting of the ice, large fresh water lakes occupied the broad valley of the Arkansas and left relics of their former presence—the extensive horizontal terraces and low table lands. This morainal matter, together with the lake beds largely cover the mining area of Leadville, and at several points afford broad gold placer grounds.

THE LEADVILLE ORE DEPOSITS.

The geology of the ore deposits of Leadville has been described by a great number of writers. The elaborate monograph of Mr. S. F. Emmons, of the United States Geological Survey, made long before the camp had attained its present development, has become classic. Since then, and with the advantages offered by the full exploitation of the district, other writers have brought our knowledge up to date. Among these might be mentioned Messrs. A. A. Blow, John F. Campion, Charles J. Moore, Max Boehmer and others, from whom, and especially from the latter, we have the following:

The Leadville ores follow the bedding of stratified Paleozoic rocks, which lie at an angle more nearly horizontal than vertical, the average dip being about 15° into the general mass of the Mosquito Range. The porphyries were forced, in a fused condition, through the crevices and cracks in the sedimentary rocks, the overlying weight and pressure of which was too great to allow them to break through to the surface. These igneous rocks, in a state of hydrothermal fusion like paste or mortar, forcing their way between the layers and bedding planes of the stratified rocks, widened and filled the cracks as they went. In this position the erupted rocks cooled and solidified. The cooling and shrinking of such large masses was slow and irregular.

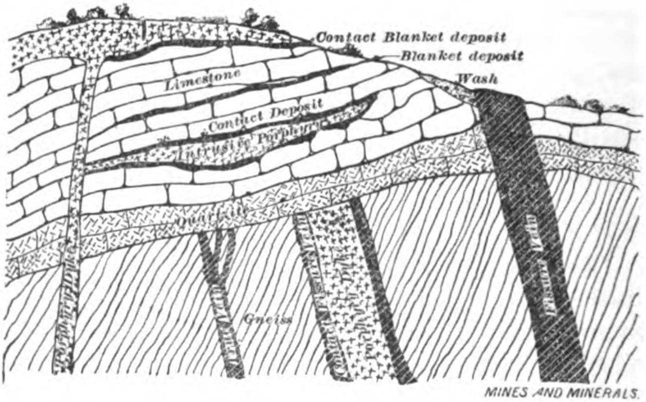


FIG. 130.—ILLUSTRATING CONTACT DEPOSITS AND INTRUSIVE PORPHYRY.

Some portions hardening sooner than others, gave rise to an uneven and loose junction and left open spaces at the contact of the eruptives and sedimentaries. It is at the contact of these two different kinds of rock that the principal ore deposits of Leadville are found. The eruptive rocks are of great variety, not so much in composition as in texture and appearance to the eye, owing mainly to the different conditions under which they cooled, crystallized and hardened. They are called porphyries, and the varieties are locally distinguished by such names as the white, gray, green, birdseye and pyritiferous porphyries.

The sedimentary rocks may preserve their regular thickness and relative position, while the eruptive continually change in size and position. At one place a porphyry fifty feet thick changes to but ten feet only a hundred feet away, and a sheet of porphyry on top of the "blue limestone" on one hill appears beneath the same rock in the next hill.

All this intrusion of eruptive rocks occurred under cover of the ocean. It was not until these rocks had cooled and hardened and the ores had been deposited that the uplift commenced which created the Mosquito range, tilted and fractured the rocks and placed them in their present position. The process of uplifting was by great folding of the sedimentary rocks and their included porphyries, followed by equally great faulting. Erosion subsequently pared down the distorted surface.

The genesis of the ores of Leadville is attributed by some geologists to leaching from the overlying eruptives because these contain in small quantities all the metals found in the ores beneath and these metals were distributed through both in nearly the same proportion. It seems more probable that both derived their metallic contents from the same source; that the solutions which deposited their burden in the form of ore bodies came from below, as did the mass of eruptive rocks; and that these solutions followed the paths made for them after the cooling and shrinkage of the eruptive rocks had left sufficient space along the lines or planes of contact with the rocks through which the eruptives forced their way. The immense ore deposits of Leadville were deposited from solutions which came from below, and which, upon reaching a certain horizon, lost their heat and consequent upward tendency, spread laterally into the adjacent limestone, and thence worked their channels downward under the influence of gravity. The direction of flow of the ore currents was generally from west to east, or southwest to northeast, because in making their own channels the solutions worked their way downward to a lower horizon to the east only and never to the west.

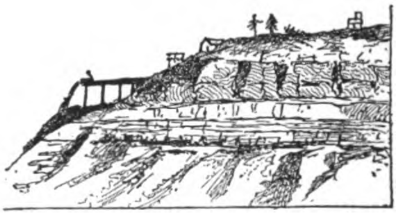


FIG. 131.—BLANKET VEINS, LEADVILLE.

Among the stratified rocks the upper or "Blue limestone" is the most prolific ore bearer in Leadville. The main vein lies at its top and directly under the principal sheet of white porphyry. In many places ore is found beneath an intrusive sheet of gray porphyry which lies near the middle of the "Blue limestone," and occasionally the currents have worked their way and deposited ore throughout the mass of both the Upper and Lower Silurian limestones down to the Lower Cambrian quartzite. No layer of ore was ever found within the main sheet of white porphyry above the limestones, and the occurrence of ore within the masses of eruptive rock has been only in the gold belt where other porphyries later than the white have forced their way across and into the overlying rocks. The ore channels have well-defined lateral boundaries, and longitudinally have been followed for lengths of from three to six thousand feet. The main channels are often united by cross channels and outside of these there is rarely much ore in the contact. Their width reaches up to five hundred feet, and the thickness of the ore is in proportion, from twenty to one hundred feet. The direction of the ore channels is generally northeast and occasionally due east.

The ore in the limestone and on top of it is generally lead ore. The ores of lower geological horizons carry less lead and more iron, and those in silicious rocks have a silicious gangue. In the lower horizon, as a rule, the ores carry better values in silver and gold, with a certain amount of copper. Near the surface the ores are oxidized, while at greater depth they are in the form of sulphides. The line of demarcation between these ores is generally quite abrupt, the change often taking place in a distance of twenty feet, not only in depth under more cover, but also in the same horizon.

The Gold Belt. Within the heart of the Leadville district a stretch of ground three miles wide and covering an area of about six square miles, including Little Ellen hill, Breece hill, Printer Boy hill and Long and Derry hill, is marked by ores containing more or less gold, in addition to the silver and the base metals which they carry. The "Blue limestone" remains as the principal zone of value. This rock and the other stratified rocks of the district underlie the so-called "gold belt" and the country beyond for miles. The eruptive rocks of this vicinity differ somewhat from those of the main district. The principal sheet of white porphyry has partly changed its position and a portion lies below the blue limestone, and the horizon above it is also occupied by sheets of gray and pyritiferous porphyry. The latter, since much of it is found overlying the gold-bearing district, is one of the rocks in connection with which the gold was introduced. The ores which came up from below are not from one, but from a number of sources, and the presence of gold in some of the mineralizing waters in certain localities would seem to account for the presence of the gold

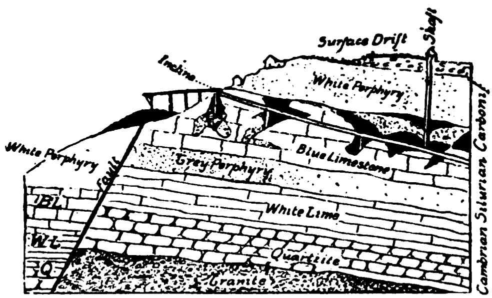


FIG. 132.—DEVELOPMENT OF A BLANKET ORE DEPOSIT, LEADVILLE, COLORADO.

belt. That the pyritiferous porphyry is intimately connected with the source of the gold-bearing ores of the main horizon seems indicated by the fact that veins of gold-bearing ore are found within the mass of the rock and at its contact with the series of Weber shales and grits belonging immediately above the blue limestone. Certain of the porphyries in the form of dikes appear to have acted as dams, arresting the values from the mineralizing solutions. The porphyry itself carries ore and can become ore under favorable conditions. The Antioch mine consists of a gold-bearing body of porphyry between walls of porphyry. The principal values are carried in a cement deposited in a brecciated zone or a fault plane.

The ores of the Leadville gold belt are found at the contact plane of the "Blue limestone," with the eruptives in the lower horizons of the limestone, and in the porphyry dikes. (Figs. 33, 34.) The gold ore within the zone of oxidation is of a siliceous character, stained with iron oxide and in many cases carrying silver and lead in considerable quantities. A great deal of the gold, especially that found in the porphyries, is in a free state; in depth auriferous sulphides are being mined from numerous fissure veins below the contacts.

The three planes on Breece Hill where gold ore is found, are above the intrusive porphyry overlying the contact proper, between the porphyry and the limestone, and in the mass of the blue limestone next to the contact. The average thickness of the porphyries in the gold belt is five hundred feet. The main chutes of the silver contact region point in the direction of the gold chutes of Breece hill. The younger and smaller eruptions of porphyry appear to have the most influence on the ore deposition. In Idaho Park the main gold deposit or zone lies between two different sheets of porphyry above the blue limestone, the gray porphyry above and the white porphyry below. Three main gold-bearing chutes have been opened. Besides dikes, the gold belt is penetrated by many gold-bearing fissures.

In 1894 the daily output of Leadville was 1,300 tons, containing silver-lead-carbonate; silicious silver and gold ore; silver, gold and iron sulphides; silver lead sulphides; manganiferous iron carrying silver.

In 1903 Leadville produced mineral to the value of $10,011,274.73. Total production to date over $300,-000,000.00

The Down Town Mines and Westerly Extension of the District. For a long period of Leadville's history mining operations were confined to the western spurs of the Mosquito Range, just east of the town, the town itself covering some four square miles of mining territory along the flatter portion of the flanks of the hills, and extending some little way out over the moraines of the Arkansas Valley. Few mines as yet extended from the hills into this "down town" area. The United States geological survey showed that there was a probability of ore-bearing strata even below the streets of Leadville, and several so-called "down town" shafts were sunk. The experiment proved successful, and the ore bodies, as well as the ore-bearing strata, were found continuous beneath the city, but with the ore was a vast amount of water. This success led to the question as to how far westward, or underneath the broad Arkansas Valley hitherto condemned as sterile, the ore-bearing zone might extend. Could it underlie the valley generally, or was its continuance abruptly terminated by a fault such as the most westerly Carbonate fault, or again if the zone did continue westward, even to the base of the Sawatch range, had it not been all scored away by the great glacier that once occupied the valley, and might not its place on the top of the underlying granite have been replaced by the heavy and deep morainal matter which the glacier dropped in its retreat and melting? There was no way to solve the question except by experimental boring. This was undertaken. Shafts were put down; the first was two hundred feet west of the Carbonate fault and encountered the well-known Leadville ore-bearing strata at a depth of two hundred feet. Another shaft was sunk four hundred feet west of the last and at two hundred and continued at a point five hundred, and later twelve hundred feet west of the Elk fault. Three hundred and eighteen feet of moraine matter were penetrated, then a diamond drill was put down one hundred and forty-five feet and struck the white porphyry. At a point four hundred feet from the Penrose mine ore was cut. Then the Bon Air was located some sixteen hundred feet west of the Penrose. So onward crept the westward advance. Later the Valentine shaft was put down twenty-five hundred feet southwest from the Bon Air and encountered the Leadville limestone.

Major Bohn estimated the area as three miles wide toward the west from Carbonate fault, extending from the city of Leadville twelve miles to the north and eight miles to the south, approximately 60 square miles. This remains to be proven and fulfilled.

CHAPTER XVI.

EAGLE COUNTY, COLORADO.

THE RED CLIFF ORE DEPOSITS.

Red Cliff is situated on the west bank of the Eagle River, in Eagle County, some forty miles north of Leadville. The general geology of the region is similar to that of Leadville, viz., granite below, on that Cambrian quartzite, Silurian and Carboniferous limestone and Upper-Carboniferous Weber grits traversed by eruptive porphyries.

Going down the valley of the Eagle River we enter a deep, narrow cañon, and look up on lofty cliffs of granite, surmounted by battlements of Cambrian quartzite and other Paleozoic strata. This is Battle Mountain, on which are the principal mines above the little town of Red Cliff.

The camp produces silver, lead and gold. The galena has changed to sulphate or anglesite instead of to carbonate, as at Leadville; but the greatest peculiarity is in the occurrence of the gold ore deposits. These are confined to cavities in the Cambrian quartzites, one of the few occurrences in Colorado where this intensely hard vitreous rock is productive to any extent of the precious metals. Above the quartzites are the Silurian and Carboniferous limestones, traversed by eruptive sheets, in which occur the usual lead and silver deposits, as at Leadville.

Mr. F. Guiterman, in the proceedings of the Scientific Society of Denver, gives an account of the peculiar ore deposits, from which the following is taken:

"The gold often occurs in nuggets. The quartzites dip ten degrees to the northeast. Between these quartzites lies the ore. The contact between the layers of quartzite is well defined. The contact filling is a breccia of fragments of quartzite, cemented with iron oxide, and at times with iron pyrites. This mineralized breccia is from four to six feet thick. The ore chimneys in this filling occur at intervals. Their presence is marked on the outcrop by what is called a '*joint clay,*' an aluminous deposit on top of the ore body, following it along the roof for about two hundred feet, then gradually thinning out and disappearing entirely when the unaltered iron pyrites are reached.

"The ore chimneys are four feet wide, the thickness being limited to the distance between the floor and the roof. The quartzite roof is always smooth, but the lower quartzite floor is rough and corrugated, and shows chemical action upon it, attending upon deposition of ore. The floor at times is impregnated with ore, not extending any great distance into it. Pay ore in the oxidized portion yields seven ounces gold and fifty ounces silver. In mining, the floor is followed as a guide. Individual ore chimneys are connected laterally by ore chutes, like a network. Ore chimneys divide and separate, the branches re-uniting or again splitting up. The whole ramification comes together again at intervals in one main chimney. The rock filling spaces where the divergence has taken place is the same as the breccia filling, only more compact and impregnated with pyrite. These fillings are left standing as pillars after mining ore.

"The characteristics of the quartzite ore deposits are: First, the outcrop of an ore chimney, with its 'joint clay,' and a zone of oxidation for 200 feet, which gradually merges as the natural water level is approached through a zone of mixed oxides and sulphides to the zones of unaffected oxides or iron pyrites. Second, the 'joint clay' gradually disappears as the sulphides of iron are approached. The silica contents of the ore in the zone of complete oxidation are 30 per cent. These lessen as the zone of unaltered pyrites is neared, down to 21½ per cent. Sulphur is present in the oxidized zone, combined with oxygen as sulphuric acid, which is united to sesquioxide of iron, forming crystalline minerals called copratite.

"In the Ground Hog Mine the ore chimneys are six hundred feet apart, but are probably connected. They abound in nuggets, some isolated and twisted like bent horns, others in a different chute, lumpy. The lumps are composed of distinct crystalline particles, cemented together by sesqui-sulphates of iron and horn-silver. Gold nuggets are found in troughs on the quartzite floor imbedded in clay associated with horn-silver. With the nuggets are lumps of sesquioxide of iron carrying much gold. This proves that the secondary deposition of gold in crystals and nuggets was through the medium of persulphate of iron derived from slow oxidation of iron pyrites. The successive developments of oxidized ore from a sulphide is thus shown. The sesquioxide of iron in the Ground Hog Mine is rich in gold, but so minutely disseminated that it will not even *pan*. Lastly, the cementing of the nuggets by sesquisulphate of iron all prove Le Conte's theory of the origin of our gold veins, as stated in his geology, pages 247-248, new edition."

The mineral production of Eagle County for 1903 was: Gold, $16,039; silver, $14,460; lead, $28,715; copper, $1,349; total, $63,563.

CHAPTER XVII.

THE PARKS AND PARK COUNTY, COLORADO.

The Parks. In Paleozoic and Mesozoic times the present valleys of North, Middle and South Parks were submerged by the sea; in Tertiary times, by fresh water lakes. The sediments of those eras still found in these valleys show that they formed a connected series of bays and arms of the sea, and later of the fresh-water lakes. In the earliest period the outlet of the North Park basin was towards the north, of the Middle Park towards the west, and of the South Park to the south. The North and Middle Parks were connected, and formed a single depression up to the close of the Cretaceous period. There was also a water connection between the Middle and South Parks; and the waters of South Park extended westward to the flanks of the Sawatch Range.

The western boundary of the Park area consisted of two distinct ridges or islands, forming a general line of elevation, parallel with the Colorado Front Range. These are the Park Range proper, on the west side of the North Park, and the Sawatch Range, now separated from the South Park by the Mosquito Range, which is the present western boundary of the South Park. Between these was the Archæan mass of the Gore Range, which formed with the southern extremity of the Park Range the western wall of the Middle Park.

Before the Cretaceous no Mosquito Range existed. Its present rocky crest then rested at the bottom of the sea. The Sawatch Range is the true continuation of the

Park Range proper, as an original Archæan land mass, which was an oval island about twenty miles long by twenty wide, surrounded by the Paleozoic seas laying down sediments against this Archæan land mass.

Through the eastern portion of this area and parallel with its longer axis now lies the valley of the Arkansas River, which in Paleozoic and Mesozoic times did not exist.

The height of these mountain masses above the adjoining valleys may have been far greater then than now, since the sedimentary beds some ten thousand feet in thickness surrounding them were formed largely out of material washed from their slopes. They were, however, not the only land masses at the time from which the material may have been derived; other land masses may have existed and have been washed away.

The ranges were not uplifted by an upthrust from below, but by horizontal, tangential pressure, resulting from contraction of the earth's crust, caused by the cooling of the interior. This is shown by the folded character of the rock masses. The tangential crushing forces were applied in one case at right angles to the lengthwise direction of the mountain mass, in the other in a direction parallel with the axis, that is north and south. As the forces of contraction became stronger and the folds were pushed closer together, the folds broke in enormous faults of many thousand feet in depth, the forces being exerted on either side towards the central mass. Eruptive rocks in many places poured through the fractures and added to the mountain masses, and their intrusions corresponded to the structural lines of greatest folding and faulting. Along the boundary of the Parks both earlier and later eruptions were so frequent that their outcrops form a continuous line.

Park County. The basin plain of South Park is covered by sedimentary rocks of Triassic and Cretaceous age, underlaid by Carboniferous and Silurian formations. These slope up to the crest of the Mosquito Range on the west, but are apparently cut off abruptly against the Archæan granite on the east, probably by a fault. The order and succession of the lower, older or Paleozoic rocks composing the Mosquito Range are here seen, together with their average thickness. First, granite, forming the base and usually found at the bottom or on the cliffs of the deepest cañons; upon this rest:

	Average Thickness, Feet
Cambrian Quartzite	200
Silurian white limestone	200
Lower Carboniferous blue limestone	200
Middle Carboniferous, or Weber grits—sandstones, shales and quartzite	2,000
Upper Carboniferous limestones, red—dish sandstones and conglomerates	1,000
Total	3,600

In some localities the total thickness will reach 4,000 feet. (See Fig. 31.)

These formations have been traversed by eruptive quartz-porphyry, dikes and sheets. The dikes occur principally in the Archæan, but there are many intrusive sheets spread out between the quartzites and limestones of the Carboniferous and Silurian. (Figs. 33, 34.)

In the central portion of the park, around Como, and stretching southward to the Platte River are the coal beds of the Upper Cretaceous. Salt springs occur in the southern end of the park, issuing from Triassic red sandstones.

In the northeast corner of the park in the granite rocks are the Hall Valley and Geneva districts, a continuation of the Clear Creek silver belt system.

The principal mineral developments are along the eastern slope of the Mosquito Range, and are formed chiefly in the Silurian and Lower Carboniferous rocks.

In the Whale mine the gneiss is intersected by numerous veins of pegmatite. The crevice is from five to ten feet, but the pay streak is from an inch to three feet wide. It is a thin vein of barite and quartz, with irregular bunches of galena and gray copper, the latter very rich in silver. The altered walls are impregnated with pyrite, galena and zincblende. The strike of the lode is northeast and southwest, and the dip is 65 degrees.

In the principal mines on Mounts Lincoln and Bross, such as the Moose, Dolly Varden and Russia, the ores are mainly argentiferous, with galena and its products of decomposition. Barite is a common gangue or veinstone in these mines. Iron pyrites, decomposed and passing into a hydrated oxide of iron, together with a black oxide of manganese, give to the ore its rusty and black appearance. The deposits occur in irregular bodies or pockets, often of great size, in the "blue limestone," near its upper surface. This limestone was originally covered by a sheet of quartz porphyry, which has been removed from the locus of the ore deposits, but still remains in various parts of the peak of Mount Lincoln. This quartz porphyry is known as the Mount Lincoln quartz porphyry, and is distinguished by its large crystals of feldspar.

The age of this porphyry is probably as late as the Cretaceous, as in the Gunnison it is found breaking through rocks of that period. In the Dolly-Varden the ore occurs in the limestone at contact with a vertical dike of white quartz porphyry. In the Fanny Barret mine, on Loveland Hill, rich deposits of galena and anglesite occur in a vertical fissure or jointing plane traversing the limestone at right angles to its dip. (See Figs. 22, 23, 24, 31.)

The Phillips mine, in Buckskin Gulch, is an immense mass of gold-bearing pyrites, deposited in beds of Cambrian quartzite, near a green porphyry dike. The Criterion, on the cliffs of the gulch, consists of large cavities in quartzite, occupied by both oxidized pyrites and galena near a porphyry dike. The Colorado Springs mine has rich deposits of galena in the white Silurian limestone in close relation to dikes of diorite and quartz porphyry.

The London mine, in Mosquito Gulch, has two strong veins of pyrites, carrying both gold and silver; the gangue of one is quartz, of the other calcite. They occur in the limestone in connection with an intrusive bed of white porphyry. (Figs. 69, 71.) The beds which contain them are turned up abruptly against the great London fault, by whose movement the Archæan granite rocks forming the eastern half of London Mountain are brought up into juxtaposition with the Silurian and Carboniferous beds at its western point. Going south along the Mosquito Range, the intrusive porphyries diminish in extent, and with them also the mineral deposits.

In the Sacramento mine rich bodies of galena and decomposed minerals have been found in a series of pockets. Some of the cavities or caverns are empty, others contain sand and decomposed pebbles of ore and other rich deposits. These deposits are not easy to follow with any certainty; open fissures lead up to the sur face of the limestone. This limestone was originally capped by quartz porphyry, which doubtless supplied the ore.

Along the banks of the Platte River are numerous masses of glacial morainal matter, consisting of bowlders and sand brought down principally from Mount Lincoln, with contributions from side glaciers of the Mosquito Range. (Fig. 11, 112, 119.)

This material, rearranged and concentrated by water, forms undulating banks from fifty to a hundred feet thick, on either side of the river, which are worked for gold with good results, especially at Alma and Fairplay.

Near Fairplay an immense amount of this morainal matter, probably resulting from the influence of several glaciers, is cut by the Platte and exposed for fifty feet. This has been worked for many years by sluice mining.

At Alma the heavy bed of *wash,* sixty feet thick, exposed on the banks of the stream, is mined by the giant nozzle. Gold, in flakes and small nuggets, has been found all through the mass in paying quantities; but the richest deposits are in the cracks and crevices of the bedrock, which is a jointed sandstone. The source of some of this gold may be a series of large but not very productive quartz veins, near Mount Lincoln, whence the glacier originated. It is also problable that a good deal came from the breaking up of the various porphyries and crystalline rocks in which it was disseminated. (Fig. 112.)

The mineral output of Park County for 1903 was Gold, $136,277; silver, $27,862; lead, $34,001; copper, $780. Total, $198,920.

CHAPTER XVIII.

PITKIN COUNTY, COLORADO.

ASPEN MINING REGION.

The production of mineral of Pitkin County for 1903 was: Gold, $4,754; silver, $1,373,591; lead, $1,409,643; copper, $1,546. Total, $2,789,534.

Every mining camp has its instructive peculiarities, and each gives its distinctive lesson. Thus in Colorado, the Boulder Co. region teaches the mode of occurrence of telluride ores; Central and Georgetown, fissure veins in granite rocks; Cripple Creek, gold ores in eruptive rocks; Leadville, "contact" veins between porphyry intrusions and limestone. If we turn now to Aspen, we have perhaps the most unique and instructive lesson in faulting, and in ore bodies connected with faulting, to be anywhere found. We have also an example of the effect of dolomization upon the occurrence of ores.

Why the little Aspen camp is such an area of complicated faulting and fracturing of the rocks will readily be perceived by its lying just in the zone between the great mass of the Sawatch Range, and the comparatively recent and violent uplift of the great lacolithic masses of igneous rock forming the Elk Mountains. The strata between these two uplifts have been squeezed, crushed, hurled up and thrown against the unyielding mass of the Sawatch Range as waves against a cliff.

Many of the strata are not only tossed upon end, but actually thrown back and doubled up upon themselves at the base of the Sawatch, as, notably, at the

Queen's Butte, near Aspen, where the Cretaceous shales are doubled on themselves, and the Trias and Jurassic rocks, which should lie beneath, lie on top. Aspen Mountain, the scene of the greatest faulting and mineralization, lies just in the narrow zone between these opposing forces. The mountain itself is a mere thin concave shell of granite, 2,000 feet high and only a mile through at the base, containing in its lap and on its sides patches of much uptilted and faulted Paleozoic rocks, from the Cambrian to the Carboniferous, the latter containing the ore bodies overlain in part by a thick sheet of diorite porphyry and quartz porphyry. (See plate in Appendix, "Tourtelotte Park.")

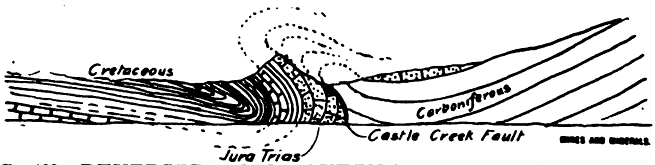


FIG. 133.—REVERSED FOLD, QUEEN'S BUTTE, ASPEN, COLO.

The following is a sketch of the general geology by Mr. J. E. Spurr, of the United States Geological Survey:

"Into the series of Paleozoic sedimentary rocks characteristic of the region were intruded in Cretaceous time rocks of igneous origin of two types, one diorite porphyry, the other quartz porphyry. Both occur as sheets parallel to the bedding of the sedimentaries. The diorite porphyry is connected with the diorite eruptions of the Elk Mountains to the northwest.

"After the deposition of the Laramie Cretaceous and the intrusion of these eruptive rocks, physical disturbances began. Among the first changes was the elevation of the Sawatch Range, so the beds which lay around its flanks assumed a dip away from the main uplift. At the same time occurred a lateral folding, due to a lateral thrust from the westward, which in the Aspen district was most pronounced in a narrow zone.

"Here an overthrown anticline was formed, culminating in a great break called the Castle Creek fault. About the same time was the development of a dome-like uplift in both granite and sedimentary rocks in a restricted region east of the Castle Creek fault, now occupied by Aspen Mountain and Tourtelotte Park. This uplift was marked on the north side by a sharp upbending of the strata. This bending up was accompanied by faulting, which has gone on continuously from that time to the present day.

"One system of faults has been faulted again by a later system. Some faults developed before and some after the ore deposition. Some faults have developed entirely in post-glacial time, and in many cases the fault movement is going on at the present day.

"*Dolomization.* Along the channels afforded by faults, hot spring waters rose and brought about chemical changes. One of these is dolomization, and at Glenwood Springs, a few miles from Aspen, the process is now visibly going on by hot ascending waters, showing it to be a chemical interchange effected between calcium carbonate in the limestone and carbonate of magnesia brought in by the circulating waters. Thus zones in the limestone, following water courses parallel to the bedding, or cutting across it, are locally altered to dolomite. There was also an earlier dolomization on a larger scale in the Silurian rocks which was produced by the action of magnesian salts contained in the waters of a shallow evaporating sea. The ores of the district are chiefly lead and zinc sulphides carrying silver, with a gangue of barite, quartz and dolomite. The deposition of metallic minerals has taken place almost exclusively along the faults, and at the intersection of two faults usually occur the richest and largest ore bodies.

"The ores were deposited by ascending hot waters. By a process of natural reduction there has been locally formed a large amount of native silver.

"The ore deposits have been exposed by enormous erosion. Since the beginning of the disturbance 15,000 feet of sediments have been removed from that part of the Aspen district lying east of the Castle Creek fault. The most recent erosion was by glaciers. A general ice sheet covered the whole of the Aspen district, moving over hill and valley westward from the Sawatch."

The discovery of Aspen followed after that of Leadville. It was observed by mining men that the same limestone formations, which are found at Leadville, circled around the Sawatch (which was at one time an island in the Paleozoic sea) to Aspen. The first discoveries of ore in the limestone belt in Spar Gulch were not very encouraging, and it was not until an enterprising company proceeded to shaft down on the back of the tilted limestone in the adjoining Vallejo Gulch, and discovered with depth vast and rich ore bodies, that the boom commenced. With these discoveries, too, began the inevitable litigation, and apex and side line contests, for which Aspen was celebrated, and which finally resulted in a compromise and consolidation of the contesting parties.

Aspen is noted for being the first to employ electric hoists and pumps in the mines. Aerial tramways to bring the ore down from such steep hills are a necessity and are much used.

On both Aspen and Smuggler Mountains long drainage tunnels have been run for drainage and extraction purposes. The longest of these, the Cowenhoven tunnel, is over 8,300 feet, designed to tap all the mines beyond the Smuggler on Smuggler Mountain.

It would be hopeless in a short article to attempt to describe the many complicated faults of the region. To give the reader an idea, however, of the state of things, we submit the accompanying diagrams taken from the Aspen Geological Atlas, which will show into what a

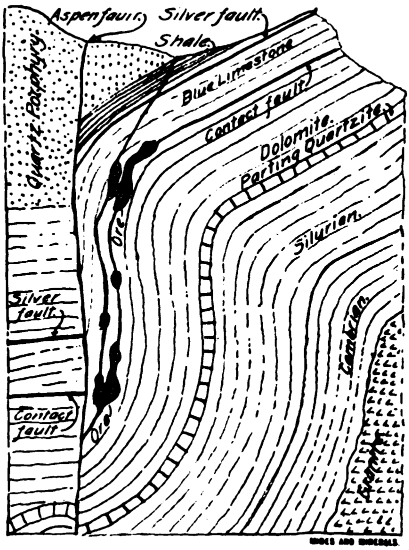


FIG. 134.—SECTION THROUGH DURANT AND ASPEN MINES, SHOWING ORE ALONG FAULT FISSURES.

checker-board the area is cut up. (See also Appendix.) There is a prominent syncline in Aspen Mountain which does not continue across the valley to Smuggler Mountain; the beds there all dip steeply and uniformly to the northwest. The amount of faulting is also much less in Smuggler than in Aspen Mountain. The Silver fault observed on Aspen

Mountain. In the Mollie Gibson mine it cuts out the blue ore-bearing limestone of Aspen Mountain and obliterates the "contact" fault which runs parallel to the bedding, and separates the blue limestone from the dolomite throughout a large portion of the district.

The mines follow the Silver fault as the chief ore-bearing locality and find all along it more or less mineralization. It is marked by a heavily brecciated zone, with solid shale and sometimes a thin band of porphyry on the west and Leadville dolomite on the east side.

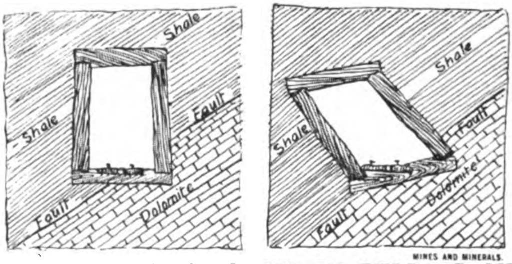


FIG. 135.—DEFORMATION OF DRIFT IN DELLA S. MINE BY MOVEMENT ALONG FAULT.

The chief ore shoots throughout Smuggler Mountain are found at the intersection of the Silver fault with another fault called the Della. This shows that the Della fault existed prior to the deposition of the ore. On the fault planes, however, crushed and broken ore is often found, showing that the fault has slipped since the ore was deposited. Mine managers find that the motion along the Della system of faults is still going on, as shown by the deformation of mine workings.

In the Mollie Gibson and Smuggler mines the ore bodies, as well as the rocks, have been extensively faulted by a comparatively recent movement. Vertical polished and striated surfaces abound.

Faulting. The most complicated system of faults is found in Tourtelotte Park, adjoining Aspen Mountain. The area is bounded on the west by the Castle Creek fault and on the east by the granite. (See plate in Appendix.)

Most of the deep cañons occupied by the principal streams of the country are outlined by profound faults such as the Castle Creek Cañon fault. Sometimes a prominent cliff shows the side of a fault, or a fault escarpment, as in Castle Butte, 400 feet high, which is the uplifted side of a post-glacial fault. The cliff face is well polished and striated by the slipping movement of the fault. Apart from other evidence, the mere existence of a fault scarp or cliff covered with striae and slickensides not yet eroded away, is sufficient evidence of the comparatively recent date of the faulting movement.

The amount of throw, or faulting, is estimated at from 2,600 to 5,000, to 6,400 and to 9,000 feet. As we go along Castle Creek Cañon, we look up at steep escarpment cliffs of granite, or quartz, with huge bodies of red sandstone and other strata that have slipped down from above, leaning against the cliff, or tossed up against it like angry cliff-climbing waves. In other places near a profound fault the strata curve down in a beautiful symmetrical arch in toward the fault.

The intersection of the two main systems of faults, the north-south and the east-west, has split up the country into many blocks, and in the process of uplifting, these blocks have been moved, one upon the other, resulting in a very complicated structure. Synclinal and anticlinal folds and corresponding faults abound.

Recent Fault Movements. That the faulting movement along the fault planes is now going on, says Mr. D. W. Brunton, is plainly proved. Survey monuments located with exactitude are found from 4 to 10 feet away from the position they occupied 10 years ago. The upper portion of many shafts has been moved entirely across the lower portion, in some cases shutting off communication with the bottom end of the shaft, in others the disjointed ends are connected by a short incline. Where the Della fault passes up through the Park Regent there is a drift along the line of this fault; the square sets assume a rhomboidal form so rapidly that the superintendent, to avoid trouble with the track, laid the rails on short ties instead of spiking them to the square-set sills, so the track could be kept up level without reference to the timber sets enclosing the drift. The accompanying illustration shows the position in which the timbers were originally placed and the position they have after being in place from one to two years.

Although we have described Aspen Mountain as a mere concave shell 2,000 feet high, about two miles long and a mile thick at the base, with a knife-edge crest on the top, yet inside this shell you may ascend from base to summit through a continuous series of connected underground workings. These are principally on the eastern limit of the synclinal fold of Aspen Mountain. In this particular region the "contact" fault between the "blue limestone" and the dolomite has been considered the best place for exploration for ore, and hence this fault or "contact" is marked all up the hill by a continuous line of tunnels.

From this outcrop the workings have gone downward following the dip to a great depth like following a coal seam in an uptilted sandstone hogback. This is especially the case in the Aspen mine. In all the mines, complicated faults are found and the ore occurs along their planes and especially at their point of intersection. In many cases, as in the Bonnybel, the ore itself is a mineralized, broken dolomite containing much barite. In the Durant mine ore has been formed in immense bodies along the various faults and fractures. The ore is found in the dolomite or "short lime" at the intersection of faults with the main "contact" fault, dolomization was attendant upon the mineralization. The Aspen Shaft bores down from above into the Durant incline below, passing through porphyry, shale and the "blue limestone" to the "contact" fault. The ore is argentiferous galena and some zincblende and is quite rich in silver.

The Durant Tunnel runs in from the base of Aspen Mountain to the deep mines for transporting ore and drainage. It begins in dolomite and in its course passes through zones of faults marked by belts of triturated matter and open watercourses.

The Argentum Juniata mine, with a certainty of encountering much water, boldly attacks by its shaft the river bottom area lying between Aspen Mountain and Smuggler Mountain. It shows that the area is not so complicated as on Aspen Mountain, the workings run on the "contact" fault between the blue limestone and the dolomite on a steep uniform dip. The Silver fault is met with and recognized by a *thick breccia or crushed porphyry shale, and limestone*, and by open fissures and watercourses in the limestone. Through these fault fractures and watercourses much water pours into the mine.

On the west side of Aspen Mountain several tunnels have been run which after going through a varying thick-

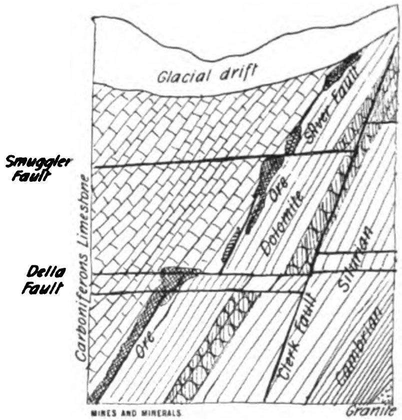


FIG. 136.—SECTION DELLA S. MINE, SMUGGLER HILL.

ness of black shale, porphyry, and quartzite, terminate abruptly against the granite skeleton of the mountain. (Fig. 136.)

In Tourtellotte Park adjoining, and geologically connected with Aspen Mountain, there are many mines of much the same characteristics as those already described. The area is a much faulted one and the ores occur in the planes or intersections of the faults.

Smuggler Mountain. Smuggler Mountain is outside the district of greatest disturbance and does not contain such complicated faulting or folding. It has, however, been a great producer and is intimately connected with Aspen Mountain across the creek, the workings in the two mountains being nearly continuous.

The so-called "contact" in the Mollie Gibson mine is the line of the Silver fault, here separating the Leadville dolomite from the Weber shales. Between these formations is a thick breccia of fragments of blue limestone and some ore. An interbedded sheet of porphyry lies in the contact near the shale. The Silver fault also encounters the "contact" fault. Both faults are marked by *crushed zones of rock* with polished walls. Other faults called the Gibson, Emma, Smuggler, Della and Clerk faults occur in the mine. The rich bodies of polybasite silver ore occur at the intersection of the faults, mostly on the Gibson fault, with polished dolomite below and shale above.

The ore contains much "polybasite" and "native silver;" the latter is derived secondarily from the rich polybasite and silver-bearing ores above. Empty cavities or "vugs" are found beautifully festooned with wire silver.

The Smuggler mine has much in common with the Mollie Gibson; the main ore occurrence is in connection with the Smuggler fault.

The Cowenhoven tunnel is the main drainage artery of Smuggler Mountain; it connects all the mine workings along the ore-bearing zone. The tunnel passes through glacial drift, white and gray limestones, Weber shales, porphyry and dolomite, but no "blue limestone." The course of the tunnel is by no means straight, but deflected at intervals on account of meeting faults such as the Della and Regent. The Della S., Park Regent, Bushwhacker, and others are all well-known mines on this little mountain, which, like its neighbor, Aspen Mountain, is riddled with a network of connected workings.

CHAPTER XIX.

THE GUNNISON REGION, COLORADO.

The geology of the western slope of the Rocky Mountains proper differs somewhat from that of the eastern slope. In the latter region the strata rest usually in their natural consecutive order from Cambrian to Tertiary upon the granite. In the western region the Cretaceous often lies directly upon the Archæan, implying that a land area existed locally raised above the Cambrian, Carboniferous, Triassic and Jurassic seas, which were depositing sediment along the eastern flanks; and it was not until the Cretaceous era that a portion of this western area, probably by subsidence, was covered by seawater and marine sediments. The coal-forming period, which on the eastern flanks occurred near the close of the Cretaceous on the western slope, appears to have occurred at an earlier date in the same age. The ore deposits which in the eastern division occur in the Archæan and Paleozoic formations, in the western occur in the Mesozoic rocks as late as the Cretaceous.

The Elk Mountains are of later origin than the Sawatch, and probably later than the Mosquito or Park Range. They are apparently the youngest mountains in Colorado. Their general geological structure is that of a great *fault fold,* an anticlinal fold or arch, running generally with the axis of the range, broken along its crest by a fault. The eastern slope of the fold is gentle, but the western is very steep, and even overturned or inverted. In the center of this fold is a mass of eruptive quartz porphyrite and diorite, which breaks through the sedimentaries, not only in dikes, but also in immense masses forming entire mountains, of which White Rock of diorite, Crested Butte and Gothic Mountain of quartz porphyrite are typical. Some of these suggest that they are remnants of laccolites, those reservoirs of molten rock from which the strata have been removed by erosion. The intrusion of these enormous masses of molten material, together with the heat engendered by the violent folding to which the region has been subjected, has produced a widespread metamorphism of the surrounding rocks. The coal is metamorphosed into anthracite, and some of the limestones are changed into white marble of superior quality. This metamorphism, combined with other circumstances, has made the region peculiarly favorable for metalliferous veins.

Topographically the Gunnison region may be divided into two parts, a northern and a southern one. The former is characterized by lofty mountains and deep cañons, with occasional parks and wide valleys, as around Irwin. Most of the northern part is included in the granitic system of the Sawatch Range, with local patches of the Paleozoic sedimentary rocks more or less traversed by great bodies of porphyry and other eruptive rocks. The southern portion is characterized by low, rounded hills of schist and schistose gneiss underlaid by coarse, massive and probably eruptive granite. These hills also may form table lands by reason of overflows of lavas, such as andesite, breccia, rhyolite, trachyte and basalt. It is, generally speaking, a schistose area of width and extent unusual for Colorado. The schists are probably of pre-Cambrian or Algonkian age. The granite indicates a once molten or highly viscous or plastic condition. Numerous fragments of schist, sometimes almost to the extent of forming a breccia, are included in it, and the schists, which often stand vertically upon it, have their pediments or bases fused into the granite, and granitic tongues and veins run up among them as from a true molten body. The schists seem to have been floated on an underlying molten or semi-molten sea of granite. The coarse red granite is at times traversed by veins and bodies of a finer grained granite. In the vicinity of Vulcan the schists are sericite-schists, composed of a silvery white mica. Locally they are veined with feldspar and chalcedonic quartz and jasper till they resemble petrified wood. Dikes of basic character occur. Resting on eroded edges of the schists, as also on nearly horizontal bodies of Dakota sandstone, are bodies of coarse andesite breccia four hundred to five hundred feet thick, forming curious hills, as at the palisades near Gunnison City. Overlying the breccia is a trachytic tuff of a porous character, perforated by numerous holes like a gigantic sponge from escaping steam. Overlying this again are basaltic flows of lava. So the geological section from the base up is:

1. Eruptive or igneous granite, containing masses and fragments of schist.

2. Upon this, Algonkian schists standing erect.

3. On their eroded edges is a belt of gently dipping Dakota sandstone.

4. Andesite breccia overlying the sandstone.

5. Rhyolite above the breccia.

6. Vesicular basalt overlying these.

The eruption of the volcanic material was after the Dakota Cretaceous and probably towards the Tertiary period.

Running through a portion of the country for many miles from Iris to Mineral Hill is a peculiar feldspathic dike composed entirely of large crystals of pink orthoclase feldspar. This *"Mother"* dike, as it is locally called, is minutely reticulated with quartz veinlets, assaying as a low grade gold ore. It appears to cut through, and fault all quartz veins met in its path. This dike is a prominent feature of the district, and seems to be the locus toward which the principal ore-bearing veins and ore zones trend. The veins in the schists are mostly small and of a lenticular character. Others are large quartz veins lying conformably with the schists or cutting across them. It would be interesting to know whether after passing through the schists these quartz veins penetrate down into the granite. Hard purple and blue quartzites, locally known as "blue veins," are rather quartzite members of the schist strata than true quartz veins. Some of the veins show pyrite and free gold.

The most interesting mine in the schistose region is the Good Hope, located on the Vulcan and Mammoth chimney, illustrating in a remarkable manner the hot spring or solfataric origin of some mineral veins. The deposits are in the zone of sericite or silver mica schists. The outcrop is a coarse breccia of quartz fragments, white, red, rusty or honeycombed, mingled with fragments of red and yellow jasper, cemented together by iron oxide and sand. The width of this rough outcrop is from five to ten feet, and it is traceable for some distance along the surface. The vein strikes east and west and dips steeply north. In the center of the successive linings of the vein walls is a dark belt composed of loose breccia or fragmentary masses of dark opal with blackish sand on either side. This zone passes into bodies of brown banded opal, or cream colored mottled opal, or into a brown veined jasper; and in one place into a saccharoidal quartz resembling maple sugar. This brecciated and variegated loose material constitutes the richest part of the ore-bearing zone. On either side of this zone is fine granular white quartz sand, slightly laminated and resulting from decomposition of the schists in place. Mingled with the sand is a fine lubricant powder of white mica from the same source as the sand. In places the sand passes into a more compact body of laminated white opaque opaline quartz like novaculite. The zone grades gradually into the sericite schist of the region. The section of the zone may be generalized as:

A central zone of fracture and principal mineralization composed of brecciated opal, jasper and black sand.

On either side of this white quartz sand, passing into laminated novaculite quartz, this again passing into sericite schist.

At about one hundred feet from the surface these zones are lined on either side by a body of granulated sulphur, five feet wide and one hundred and five feet deep. Below this is a quicksand of loose disintegrated iron pryites, in depth passing into a body of solid iron pyrites.

Remarkably fine specimens of native tellurium have been found in the Good Hope mine, and petzite and a telluride of copper have also been detected. The opaline deposits, especially those marked with purple spots, assay very high in gold. The sulphur also assays from 3 to 4 dwt. in gold, but the pyrite seems to be low grade. Free gold can easily be seen in the banded opaline rock. (Fig. 137.)

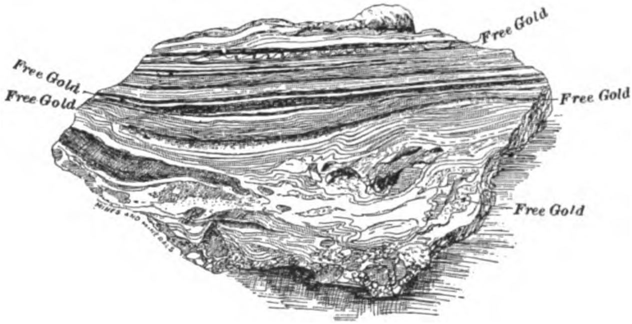


FIG. 137.—RIBBON-VEINED JASPER, CARRYING FREE GOLD, VULCAN MINE, GUNNISON, COLORADO.

The origin of the deposit, as well as its minerals, seems analogous to that at present in active operation at Steamboat Springs, Nevada, and at Sulphur Bank, California. Hot waters, accompanied by steam and gases, ascended through a line of fissure or weakness in the schists, dissolving out silica from the rock through which they passed and depositing it in a gelatinous condition on either side of the line of fissure. From this central brecciated opaline zone thus formed, the steam and gases penetrated the adjacent schists, decomposed these for some width on either side and leached their iron, setting free the mica and quartz as quartz sand and mica dust. The same waters, probably, charged with sulphuretted hydrogen, were laden with the elements of iron pyrites carrying gold and may have reached the upper oxidized zone as a body of pyrite and quartz now oxidized into a very porous mass of gossan. Lower down the pyrite may have been desulphurized by waters ascending through a later fracturing of the vein, leaving in place of pyrite a body of native sulphur. Below that, is the bed of disintegrated pyrite and finally the unoxidized pyrite vein to depths unknown.

The ore deposits in the Ruby and Irwin districts are in veins which traverse the Upper Cretaceous rocks and penetrate the Cretaceous coal horizon. Ore occurs at a great many localities in the Elk Mountain region and the principal mining centers lie both in Gunnison and Pitkin Counties.

Independence is on the west slope of the Sawatch Range. Here sulphuret ores, carrying silver and gold, occur.

At Tin Cup, near Alpine Pass, the Gold-Cup mine is in the Carboniferous limestone similar to that at Leadville; the ore is argentiferous carbonate of lead, and oxide of copper.

At Irwin, the Forest Queen mine occurs in a vein associated with a vertical porphyry dike traversing the Cretaceous sandstones. The ore is ruby-silver, arsenical pyrites and sulphurets of silver. The gangue is an indistinctly banded quartz.

On Copper Creek, near Gothic, a series of nearly vertical fissure veins traverse the eruptive diorite rocks. These veins are mineral-bearing, and at the Sylvanite mine have produced very rich ore, with very large masses of native silver, in curly tow-like bunches. Some of these silver curls are tarnished into a bright golden color.

Professor Benjamin Sadtler has shown that a large area around Pitkin will be available for ore production in the future, of which but little was suspected in the past. He says, "The record of diamond drill borings and other stratigraphical explorations in Gunnison County show that Hayden's map marks as unproductive granite a large area overlain by Paleozoic strata more or less ore-bearing and profitable." With an increase in the price of silver, a more thorough exploitation of this region will doubtless be made.

Gunnison County is credited with a mineral production for 1903, as follows: Gold, $18,533; silver, $34,981; lead, $5,409; copper, $1,985; zinc, $3,002. Total, $93,910.

THE SAN JUAN REGION.

The area now occupied by the great San Juan region was at a very early period a granite island around which a considerable thickness of Algonkian sediments was deposited. These were subsequently uptilted by the elevation of the granite, and on their eroded surfaces was deposited again in marine waters a vast series of sediments from the Cambrian to the Tertiary. By either a continuous or a secondary elevation of the plateau these sedimentary rocks were also uptilted and eroded, and on their eroded surfaces, together with that of the earlier granite and Algonkian rocks—quartzites, schists and slates—was poured out, in Tertiary times, a vast series of volcanic rocks, consisting of monzonites, diorites, porphyrites, andesites, including andesitic breccia and rhyolites. The present thickness of these volcanic sheets is estimated at 5,000 feet, and before erosion, was probably considerably more. The area also now covered by these volcanics was originally much greater than at present represented. The earlier flows of lava were penetrated by still later dikes and intrusive sheets varying in com-

FIG. 138.—THE VOLCANIC MOUNTAINS OF THE SAN JUAN REGION.

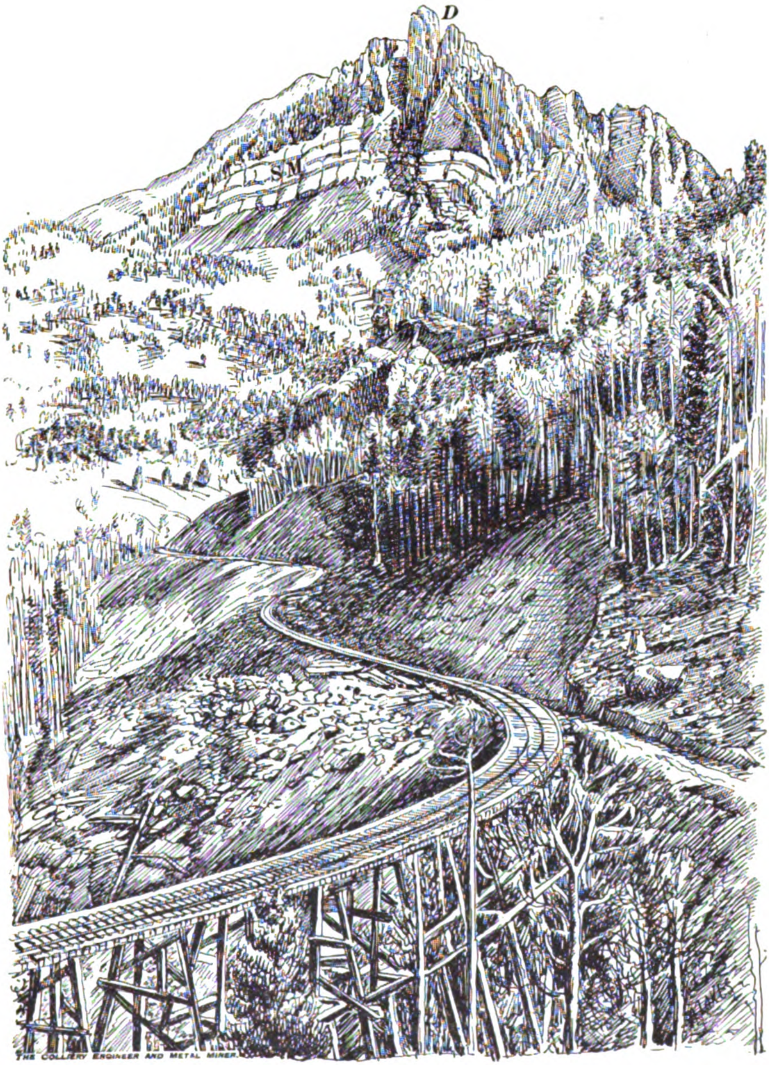


FIG. 139—PORTION OF SAN JUAN REGION—VOLCANIC CONGLOMERATES AND ANDESITIC BRECCIA RESTING ON UPTURNED ALGONKIAN SCHISTS AND QUARTZITES.

position from gabbro to granite. The high mountains of Silverton and Telluride were near the center of volcanic activity at its maximum. The general center of the vol-

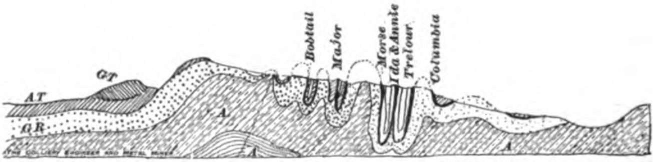


FIG. 140.—SECTION OF MINE NEAR SUMMITVILLE, COLORADO.

canic area has been the site of several great disturbances in earlier geologic times. "There may have been," says Mr. Cross., "several centers of eruption whose products combined to form the great complex."

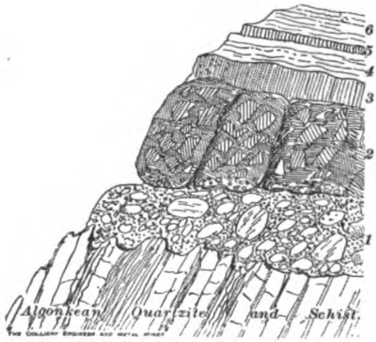


FIG. 142.—VOLCANIC BRECCIA AND CONGLOMERATE RESTING ON TILTED ALGONKIAN QUARTZITES, MEAR'S ROAD, SAN JUAN.

A considerable area covered by a series of tuffs and agglomerates of andesitic rocks, known as the San Juan formation, appears to be a water-laid formation, probably in a great lake covering part of the region. The San

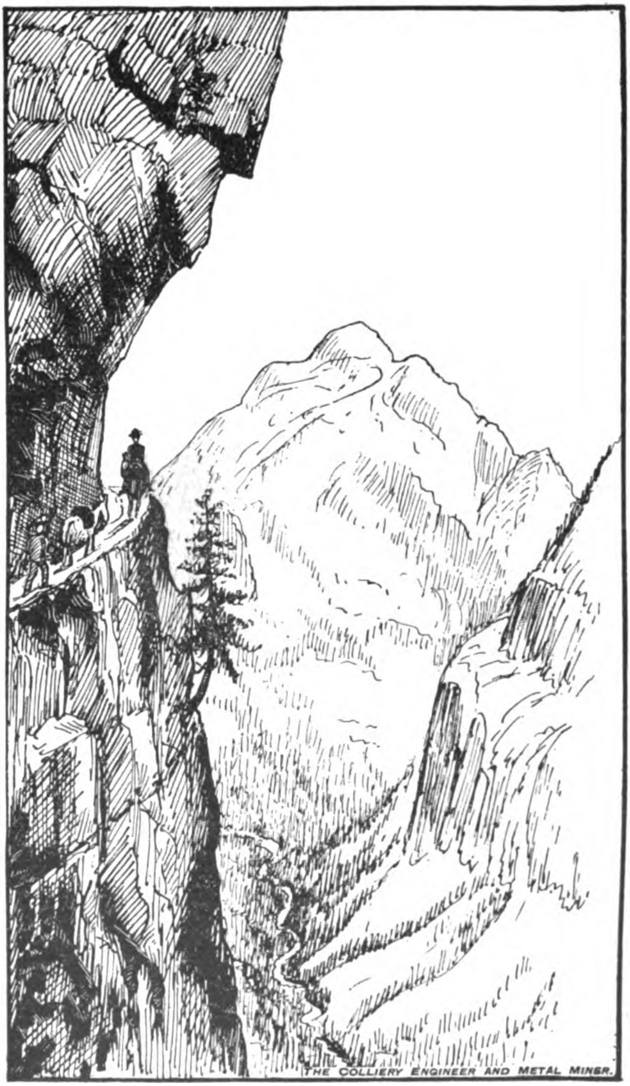


FIG. 141.—A STEEP MOUNTAIN TRAIL, SAN JUAN.

Juan formation is more or less perfectly stratified and no lava flows have been observed in it. The greatest known development is on either side of Canyon Creek, where it reaches a thickness of about 2,500 feet.

FIG. 143.—WATERFALLS FOLLOWING COURSE OF FISSURE VEIN, ANIMAS CANON, SAN JUAN.

The Silverton series consists of a complex of andesitic flows and tuffs alternating with rhyolitic flows, flow-breccia and tuff. The series varies from 400 feet to 5,000 feet in observed thickness.

The Potosi series is almost exclusively rhyolitic. At a later period than that of the Potosi rhyolitic eruptions, there were stock eruptions penetrating the whole series of surface volcanics to the summits of the highest mountains.

The lode fissures are very numerous and radiate in many directions; a prevailing one is northeast by southwest. Some of these fissures are clean cut single fissures.

FIG. 144.—HORSES IN FISSURE VEIN, SAN JUAN REGION, COLORADO.

Others belong to the sheeted zone class, and others are congregated or linked fissures. Some large so-called *"chimneys"* appear at the junction of several fissures as in the Red Mountain district. But little faulting or displacement is observed; in a few cases, however, later fissures fault older ones. The fissures were formed by tangential stress caused by local gravitative adjustment of the rocks after the outpouring of the volcanics. Mr. Ransome estimates the depth at which the fissures were formed at about 6,000 feet.

In this region almost all the ores known in Colorado are represented. The gangue or vein stuff is commonly quartz, associated locally with barite and rhodonite, or

FIG. 145.—SPLIT VEINS, ANIMAS CANON, SAN JUAN.

rhodocrosite. Mines are very numerous and among them some of the most noted in Colorado. While a large proportion of the mines are in ordinary fissure veins, a few of them are peculiar, such as those of the Red Mountain

FIG. 146.—ANDESITIC BRECCIA.

district, and the cave mines in Mesozoic quarzite in the American Nettie Zone or Gold belt of Ouray.

The ore deposits of Rico, as illustrating peculiar phases in ore deposition, will be separately described.

THE AMERICAN NETTIE.

The mining town of Ouray, Colorado, is located in a deep, pitlike depression. It is surrounded on all sides by lofty, precipitous mountains with steep cliffs. South of the town these mountains are composed on top of a thick, massive formation of andesitic breccia. This rests

FIG. 147.—VEINS BRANCHING FROM A MAIN VEIN, HOWARDSVILLE, ANIMAS CANON, SAN JUAN.

on upturned Algonkian schists and quartzites and more horizontal Paleozoic strata. The northern portion of the depression enclosing the town is of massive red Jura-Trias conglomerate overlain by softer shales and sandstones of the Jurassic, capped with a thick bed of Dakota Cretaceous quartzite containing the ore bodies. This is overlain by about 100 feet of marine Cretaceous shales, capped in turn by intrusive sheets of porphyrite and by a body of gray andesitic breccia. The whole mass of sedimentary and of igneous sheets is traversed by numerous narrow dikes of porphyrite and breccia.

The American Nettie is located in what is known locally as the Ouray "gold belt," a zone of quartzite extending for some miles and noted for its gold bearing qualities. This zone occurs on either side of the canon of the Uncompahgre River. At the American Nettie the

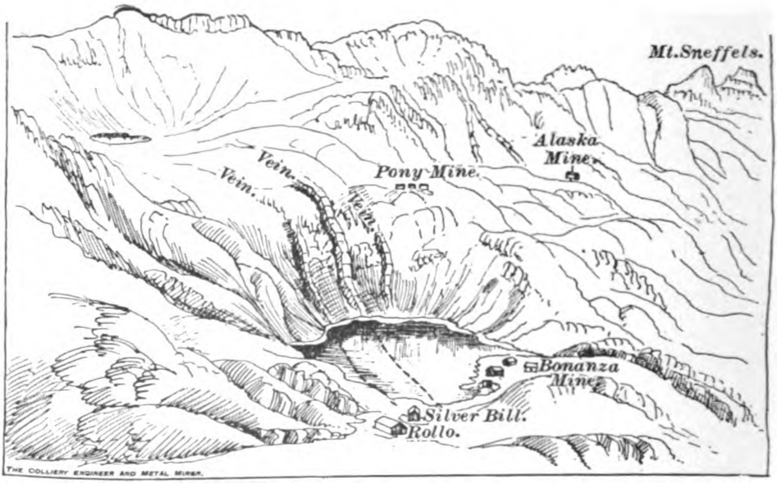


FIG. 148.—PARALLEL FISSURE VEINS, LAKE COMO, SAN JUAN.

jointing and stratification planes of the quartzite have been enlarged and hollowed out into small caves following down the gentle dip of the strata. These cavities, from an inch or two to eighteen feet wide, are somewhat flattened and elliptical in shape. Some are empty, smooth and apparently water worn. Others are lined with quartz crystals or gouge. Sometimes part of the cavity is filled with oxidized ore, or in part with sulphides, or in part with quartz crystals. In many of the cavities the ore is loose and friable. Again the ore may occur more in the form of veins lining the shearage cracks. The narrow dikes of breccia often make ore at contact with the quartzite, though themselves nearly barren. Above the quartzite lies the impervious black shale and at the contact the ore ceases. Ore is more

FIG. 149.—ANIMAS FORKS, SAN JUAN.

abundant in proportion to the greater metamorphism of the sandstone.

The origin of the ore deposits seems connected with the intrusion of the dikes, the ascending hot vapors of which may have metamorphosed the sandstone, and heated solutions excavated the caves and subsequently deposited the ore. In the caves the ore is usually very varied and rich. They contain copper and iron pyrites, galena, zincblende, telluride of gold and bismuth and sometimes free gold.

LA PLATA REGION.

This district comprises a compact little group of lofty mountains on the southwestern border of the San Juan

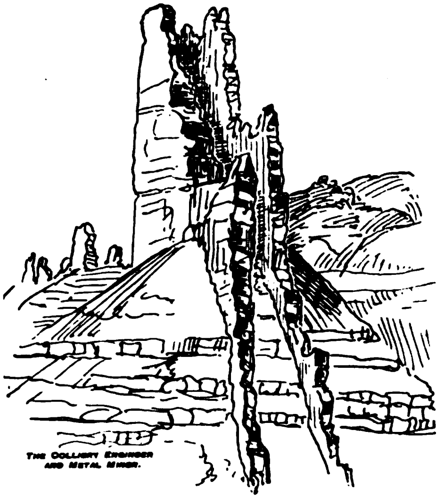


FIG. 150.—DOUBLE DIKES, SAN JUAN REGION.

Range. These mountains are an extraordinary example of the intrusion of volcanic rocks into the sedimentary strata of the Jura Trias and Cretaceous periods, forming laccolites and intimately connected with the mineralization of the area. The intrusive rocks are syenites, diorites and monzonites, with later dikes of lamprophyre. The intrusions of all these igneous rocks into the sedimentary beds has made a domal uplift of the whole body of strata. Later intrusions also forced their way across the sedimentary beds, and these intercalated porphyries formed stocks within the mass. One effect of these igne-

FIG. 151.—STRUCTURE OF LA PLATA MOUNTAINS.

ous intrusions was to greatly metamorphose the sedimentary beds.

INTRUSIVE PORPHYRIES, LA PLATA MOUNTAINS.

(After Holmes.)

At a later period than any igneous intrusions the La Plata uplift became the seat of extensive deposition of

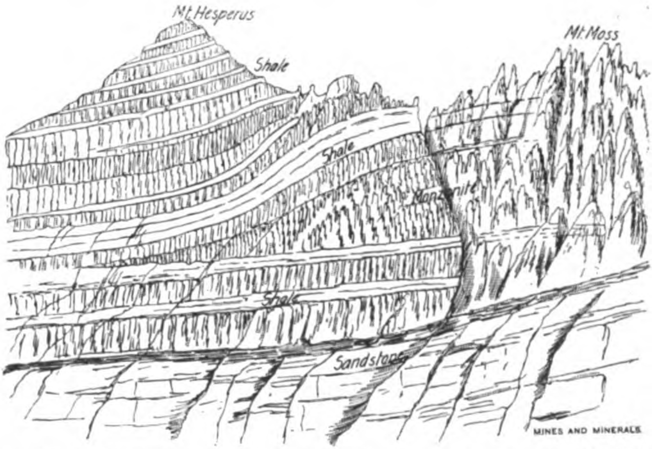


FIG. 152.—INTRUSIVE PORPHYRIES, LA PLATA MOUNTAINS.

ores of iron, copper, lead, zinc and telluride ores carrying gold and silver, with the gold predominating. Native amalgam and realgar also occur. The uplift was in the

Tertiary period and was caused by the upward pressure of the molten magma beneath. The upheaval was followed by greater fracturing and fissuring of the strata, and the fissures were subsequently filled with veins.

The telluride ores occur in flakes in dark, fine-grained quartz veins, especially in the eruptive rocks. Sandstone

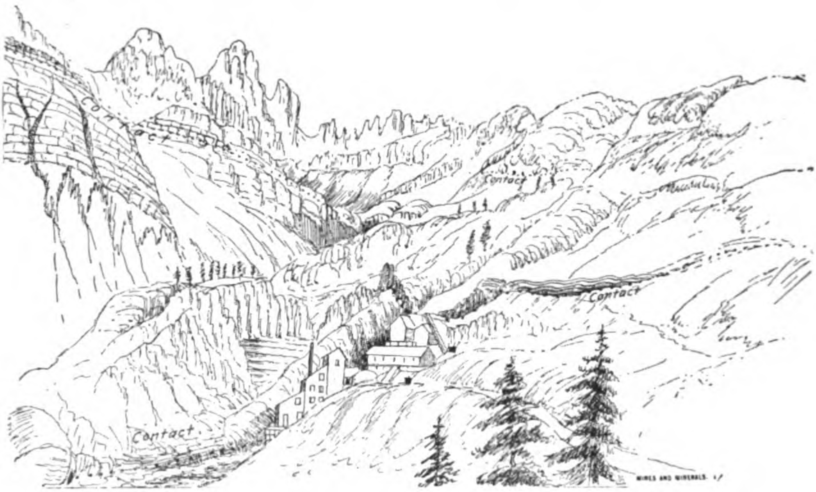


FIG. 153.—THE MANCOS CONTACTS AND LITTLE KATE MILL, LA PLATA MOUNTAINS.

layers have in places been heavily impregnated with iron pyrites, which in some cases, as at the Mancos contact, carry gold in paying quantities. The ore of the La Platas was probably derived from the basic constituents of the igneous rocks and ascending solutions were the means by which it was deposited.

THE NEEDLE MOUNTAIN DISTRICT.

Between the La Platas and the San Juan Range is the Needle Mountain district. It is largely of granite rocks and Algonkian quartzites, containing many large veins of quartz, carrying both silver and gold-bearing ores, together with some copper sulphides.

CREEDE CAMP.

The rocks about Creede are all volcanic, mostly rhyolites, andesites, andesitic breccia and quartz porphyry. The veins are for the most part strong fissure quartz veins, traceable for many thousands of feet, and showing all the leading characteristics of fissure veins, such as a

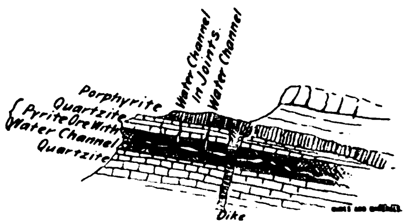


FIG. 154.—MANCOS CONTACT ORE DEPOSIT.

ribbon or banded structure of the quartz parallel with the walls, with a comb or vugh of quartz crystals in the center, often of a beautiful purple amethystine color. Some of the ore deposits lie in shearage zones in the volcanic rocks, others in zones of breccia and local decomposition between the cleavage planes or lines of fracture of the massive rocks. It is essentially a lead-silver camp. One side of the cañon called Bachelor Mountain, is strongly silver-lead, the opposite side is more essentially lead, in a soft, decomposed gangue. Some of the ores are straight smelting ores, others require concentration. The ores in some veins are silicious. As a rule the ore is remarkably solid from wall to wall. Barite, oxide of iron and manganese occur; also native and horn-silver.

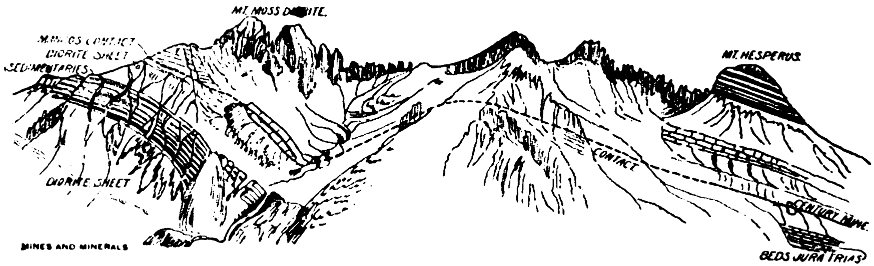


FIG. 155.—MANCOS CONTACT, LA PLATA MOUNTAINS.

FIG. 156.—THE SAN JUAN MOUNTAINS, COLORADO, SHOWING NEEDLES IN DISTANCE.

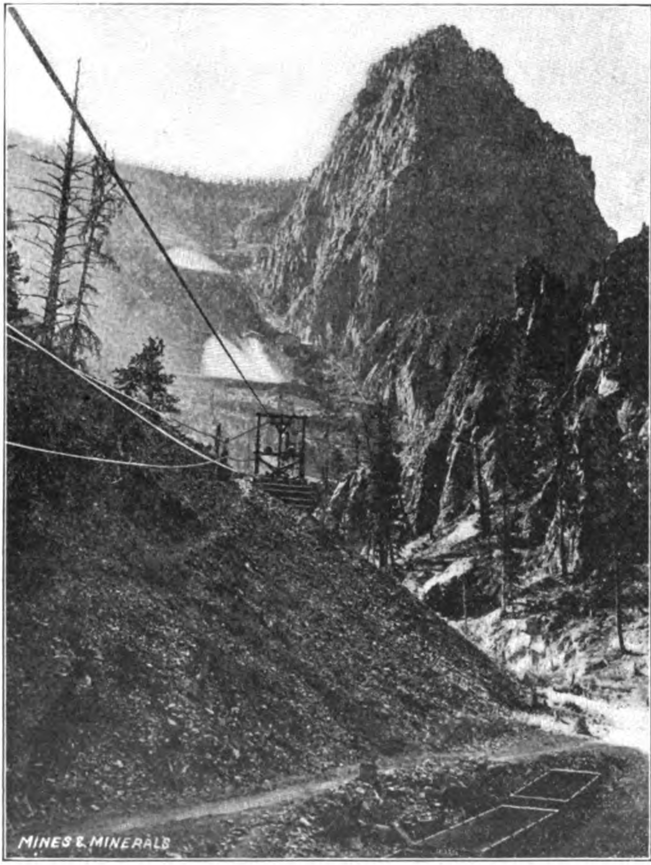


FIG. 157.—WIRE ROPE BUCKET TRAMWAY, CREEDE, COLO.

CHAPTER XX.

THE TELLURIDE DISTRICT, AND THE SMUGGLER UNION MINES.

(By T. A. Porter.)

"The geology of this district is characteristic of this portion of the San Juan region. The tremendous cliffs and mountain plateaux on either side of the San Miguel River are formed on top by a huge mass of andesitic breccia. Below this volcanic cap is the San Miguel conglomerate, a sedimentary deposit composed of very large granitic pebbles with but little volcanic material. Upon this rests a stratified water-laid series of volcanic tuffs and breccias, constituting the lower member of the volcanic complex. This bedded formation of andesitic debris is between 1,000 and 2,000 feet thick. This series is called by Cross the San Juan formation. The whole series, together with the underlying Mesozoic rocks, are cut by later dikes and stocks of diorite.

The Smuggler vein, and in fact most of the productive veins of this region, are confined to the upper, or volcanic series, though the fissures doubtless penetrate the underlying water-formed rocks; but what their values are in these lower formations has not been satisfactorily proven. The general impression is that the veins lose values on entering the sedimentary beds.

The Smuggler vein is remarkable for its continuity and regularity. It cuts into the volcanic rocks, which are here 3,000 feet thick. The vein is plainly visible upon

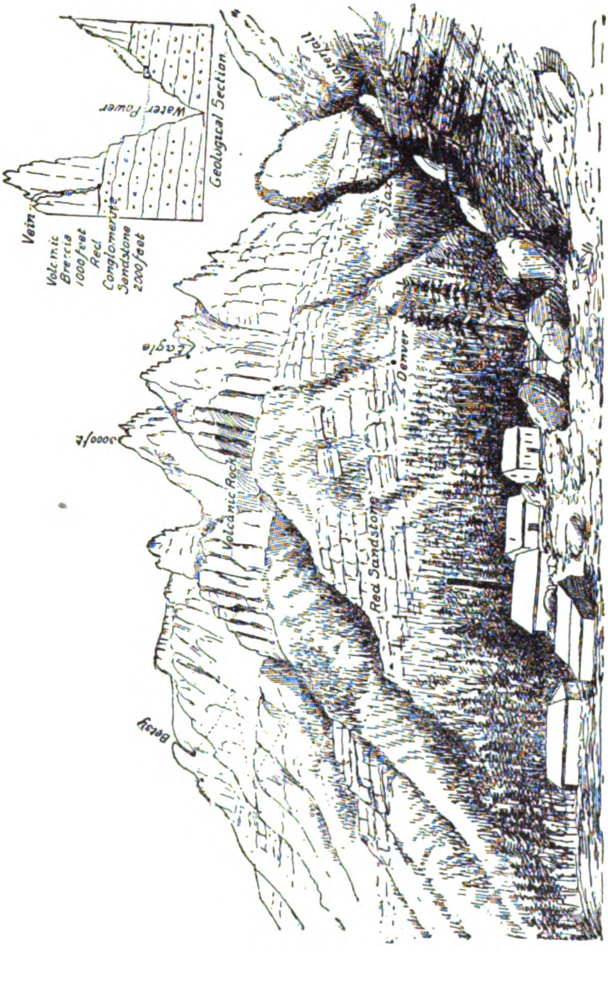


FIG. 158.—STRUCTURE OF THE TELLURIDE REGION—VOLCANIC BRECCIA ON SEDIMENTARY ROCKS.

the surface where it crosses the divide and cuts through the rhyolite and andesite, down into the andesitic breccia to within a few hundred feet above the conglomerate as it crosses Marshall Crest. It is traceable for several miles and is exposed by mine workings for four miles. Its course is north 20° W., and dip westerly at an angle of 75°. Two cross faults occur, the displacement being about fifty feet. One fault is caused by a large quartz vein called the Pandora, containing gold, but little silver. The other is caused by the Revenue vein

FIG. 159.—TREE SPLIT BY LANDSLIDE, TELLURIDE DISTRICT, SAN JUAN.

crossing the Smuggler at an angle of about 15°, and is well defined. It carries less gold and more lead than the main vein. The Smuggler vein is a fault fissure, both hanging and footwall show large polished surfaces. Striation is very frequent, and gouge matter several inches in thickness occurs upon both walls, in other places the quartz is "frozen" to both walls. The average thickness of the vein is five feet. Quartz and rhodocrosite are the gangue matter with calcite and barite. The minerals are pyrite, chalcopyrite, galenite, sphalerite and the arsenical silver minerals. A remarkable feature of the vein is the regular and continuous distribution of the ore which generally lies near the foot wall. There is a constant increase in gold values toward the south."

THE RED MOUNTAIN DISTRICT.

(By T. E. Schwartz.)

"The Red Mountain District occupies the basin at the head waters of Red Creek from Ironton Park to the Divide, a distance of six miles.

The formation on the two sides of Red Creek are very dissimilar. On the east side, upon which are the mines,

FIG. 160.—RED MOUNTAIN DISTRICT, SAN JUAN.

the Red Mountain presents a very rough exterior with jagged cavernous cliffs, long stretches of slide rock, and bright red colors. A series of benches form the base of the mountain to a height of 400 to 800 feet, characterized by quartz outcrops. These outcrops form knolls, rising 200 feet above the surrounding surface. Many present a pyramidal appearance with a cliff of hard blackened cavernous quartz for apex. At the south end of the district two small parks occur, nearly surrounded by these massive outcrops, marking the location of many of the producing mines.

The Red Mountain District has been the scene of intense metamorphism. The andesite is bleached over large areas, full of kaolin, breccia and pyrite. The white,

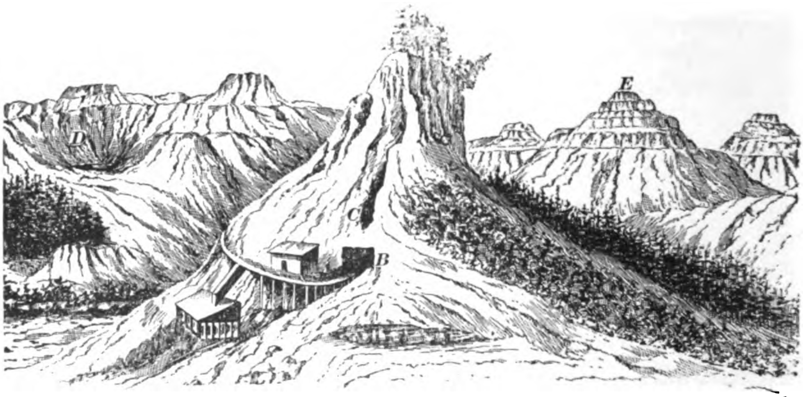


FIG. 161.—NATIONAL BELLE MINE, RED MOUNTAIN, COLO.

soft rock with kaolin faces encloses most of the ores. Massive knolls of quartz or silicified andesite are, in the National Belle and other mines, penetrated by caves and irregular passages, sometimes forty by sixty feet, filled with iron oxide, white kaolin and ores of secondary deposition. These caves extend in depth to the water level nearly two hundred feet below the outcrop. Their walls are smooth and rounded, sometimes hard, but generally of porous silicious rock.

The ores are of two classes, surface ores or those of secondary formation, and sulphide ores or those occurring below the former water level. The ores of the first class are found in the caves, either adhering to the walls on masses of stalactites, or else as loose sand carbonates, or

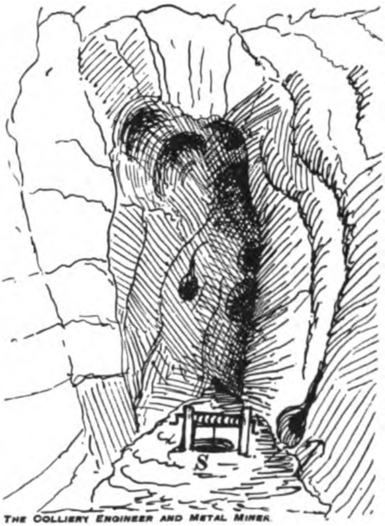


FIG. 162.—JEDD CAVE MINE, SAN JUAN.

a clayey mixture with kaolin, heavy spar, and detached masses of ore and rock. The ores of the National Belle, Vanderbilt and Grand Prize carry a heavy per cent. of lead. The ore in the Enterprise carries from 25% to 30% bismuth, from which has been reduced several hundred pounds of metal 98% fine; the first large lot of metallic bismuth reduced on this continent.

The ores of the second class make the bulk of the Red Mountain production. In mines producing the oxidized ores peculiar to caves the unoxidized ores begin at water level, where the cave ores cease. In other mines, where the cave formation is not present, the latter class of ores outcrop on the surface, and there the quartz knolls do not occur. These ores are sulphides and sulpharsenides, producing galena, copper and iron pyrites, erubescite, bismuthinite, enargite and tetrahedrite. Associated with these ores are rhodonite, gypsum and barite.

In the National Belle, Enterprise and Hudson, enargite occurs massive, and is the prevailing mineral below the horizon of oxidation, varying greatly in silver contents from fifteen to a hundred and fifty ounces per ton, associated with low grade iron pyrite, zincblende and lead, or bismuth sulphide.

In the northern portion of the district are two producing mines, the Yankee Girl and Silver Bell. High grade ores of the Silver Bell are characterized by bismuth, whilst in those of the Yankee Girl stromeyerite is the principal mineral. Carloads from the Yankee Girl return at times 3,500 ounces of silver to the ton, with 30% copper. The Silver Bell produced in large lots bismuth ores, milling 500 to 1,000 ounces in silver per ton. The bulk of the Red Mountain ores at present carry from 5% to 20% of copper.

The surface ores in this portion of the district are either galena, or pyrite, or copper pyrite. The change in character and grade of ore is sometimes rapid. The prominent features of their occurrence are: that the ores occur in chimneys with small horizontal section, more or less circular. The matrix is usually a hard, fine-grained brown or grayish quartz, often very porous. The ore is concentrated in one portion of the chimney, or embraces the whole of it, massive and quite free from gangue for considerable distances. The rock enclosing the chimneys is soft, white andesite, occupying large areas, separated from each other by hard, fine-grained, blue-green diorite; the latter destitute of ore. Chimneys, separated by areas of diorite, are foreign to each other and show dissimilar ores. The change from *white rock* to diorite has no regular course. Changes in direction or pitch, often quite sudden, are accompanied by an enlargement of the chimneys. Every chimney is connected with one or more cleavage or fracture planes, generally vertical. The alteration of the enclosing rock increases as the chimney is approached, more silver occurs, and cleavage faces with large or small masses of kaolin. Notable instances occur of marked increase in grade of ore with considerable depth. In the caves the reverse often happens. Ores in the caves are richer than the unoxidized ores immediately below them. The mines by no means grow richer with depth. Copper and bismuth are the main enriching elements, iron and lead the poorer.

It is evident the district has been one of great activity of heated mineral solutions, which have deposited their contents along nearly vertical channels, and that such channels have been formed along planes produced by cooling of heated rock masses, or by some near dynamic movement. Owing to the structure of the rock, with its network of planes, the circulation of these solutions must have been comparatively rapid. The strong, horizontal planes which formed drainage courses for large areas, collecting their mineral contents or solution, might be expected to play an important part in determining the character of the ores in the chimneys with which they are connected. It seems that the alteration of the country rock and the deposition of the ores was a simultaneous process. The general merging of ore into rock on one or more sides of the chimneys and gradual change of the hard quartz into soft andesite, together with the presence of kaolin in and adjoining the ore would indicate this.

The absence in the formation of extended fractures of considerable lateral persistence accounts for the non-formation of ordinary fissure veins. The nature of the rock and the forces governing the subterranean circulation favored their concentration at points of least resistance along vertical planes. In their passage upwards a gradual deposition of mineral contents and a replacement of

FIG. 163.—CAVE ENTRANCE, NATIONAL BELLE MINE.

portions of the adjoining rocks took place, forming chimney-shaped deposits, lacking in the confining walls and resulting regularity of fissure veins. The carbonate ores result from action of surface waters upon original sulphides, pyrite, galena, etc., found below, an action which concentrated the silver and lead, other constituents being carried off in solution. The oxidizing and dissolving properties of these waters account for the formation of caves along cleavage and fracture planes and the redeposition of ores upon their walls.

THE RICO MINING DISTRICT.

This mining camp is in the eastern part of Dolores County and southwest from Telluride. The general geological features of the district are similar to those at Telluride, but the ore deposits and their mode of occurrence are peculiar. A description of the ore deposits of Newman Hill, by Mr. J. B. Farish, will give the best idea:

"In the neighborhood of Rico sedimentary beds are found from the Lower Carboniferous to the top of the Colorado Cretaceous. The elevation of the mountains was associated in its origin with the upheaval of a great diorite laccolite, from which the strata dip off in all directions up to 25¢. The mountain is much faulted. Ore bodies occur mostly in the Carboniferous series, on both sides of the Dolores River.

Newman Hill forms a bench-like extension of Dolores Mountain. The lowest exposures at the foot of the hill on the banks of the river consist of a stratum of magnesian limestone, impregnated with chloritic matter. In this are large bodies of ore, principally iron and copper pyrites, and zincblende, running low in silver. It is difficult to mine here on occount of carbonic acid gas rising from subterranean carbonated waters, which, when reaching the surface, form soda springs. The limestone is charged with free gas. Shallow openings are quickly filled with the gas, and birds and animals venturing into them, perish. The gas permeates the overlying strata; also vitiating the air in the upper mine workings. On this limestone are alternate strata of sandstone and

NEWMAN HILL, RICO.

shales for a thickness of 500 feet, followed again by a band of limestone, and that by more shales. The total thickness of the section is about one thousand feet.

Fifty feet above the magnesian limestone a tongue from the laccolite intrudes between the shales and sandstones. It is about two hundred and fifty feet thick. This intrusion of porphyry is connected with the origin of the ore deposits, for the rock itself is sometimes replaced by pyrites. The rock is a porphyritic diorite or porphyrite consisting of hornblende, augite and feldspar.

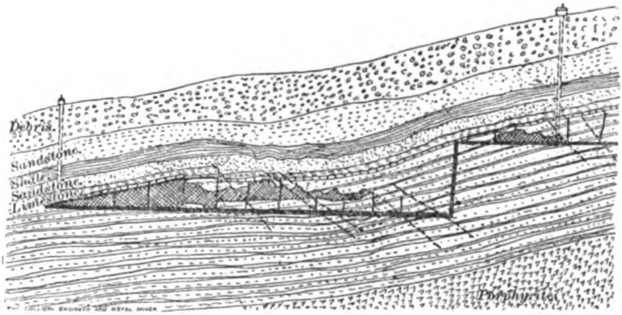


FIG. 164.—SECTION OF ORE DEPOSITS, NEWMAN HILL, RICO, SAN JUAN.

The limestone belt midway up the hill called *contact limestone* is from eighteen to thirty inches thick. It is enclosed between beds of shale. The upper shales are soft and drab color and from six to twenty feet thick, forming an impervious shed to the waters circulating above. The underlying shale is black and about twelve feet thick, resting on sandstones and shales. The top of the bench is covered three hundred feet with debris. The cliffs, rising above the summit of the Newman Hill bench, being part of Dolores Mountain, are alternate bands of limestone, shale, conglomerate, and sandstone, followed above by the characteristic red and variegated strata of the Jura-Trias, and these again by the shales, limestones, etc., of the Cretaceous. The average dip or inclination of the strata on Newman Hill is about 15° southeast.

Ore deposits occur: First, on vertical fissures; second, on another series of fissures whose inclination is

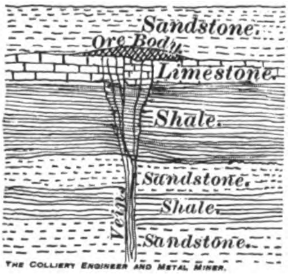


FIG. 165.—FEEDING VEINS, ORE BODY AND FAULT, NEWMAN HILL, RICO, COLORADO.

about 45%, crossing the vertical fissures at various angles; third, along a horizonal contact plane between the so-called *contact limestone* and the overlying shales. .

The vertical fissures are the richest in ore and are locally called "vertical pay veins." The cross vein fissures have less ore and are lower grade. Both systems of veins are in fault fissures, the amount of slip or displacement is about twenty-five feet. The fissures vary in width from a few inches to several feet. The veins show all the true characteristics of fissure veins, such as slicken-sided or polished walls, gouge, and a ribbon or banded arrangement of the vein material. In longitudinal extent the fissures show great strength, some of the vertical ones can be followed for upwards of 4,000 feet.

There are five principal veins, the Swansea, Enterprise, Hiawatha, Jumbo and Eureka. The lowest workings are in the Enterprise, 200 feet below the *contact limestone.* The veins are strong and regular until the black shale is traversed by them, when they split up into

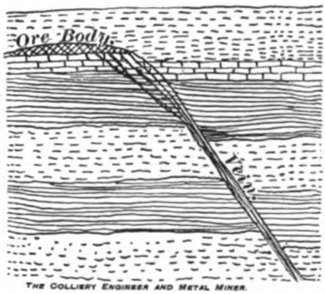


FIG. 166.—FEEDER VEINS, NEWMAN HILL—ORE DEPOSITS.

veinlets on shale and lime, replacing the latter at times with ore until the overlying bed of shales is reached. The greatest deposit is on the contact plane by horizontal ore bodies in the form of a *pipe,* varying from two to twenty feet in thickness. These pipes lie directly over the vertical fissures. The fissure veins do not extend beyond the *contact limestone.* The fault fissures doubtless extend above the *contact lime,* but they are so tight that they can not readily be discerned. There is a close relation between the contact ore *pipes* and the underlying fissure veins, where the latter narrow, the ore pipes also narrow.

The cross veins are narrower than the verticals and their displacement is less. The cross veins also separate and split up into veinlets on entering the shale below the *contact lime.* The ore pipes do not cover them, but make to one side of them. Horizontal ore bodies connected with these leading cross veins are from twenty to forty feet wide and from a few inches to three feet thick. Where the cross-veins join or pass the vertical veins they always disturb the latter.

The vein filling or gangue of the vertical fissures is a glassy, white quartz, with vughs or crystalline cavities.

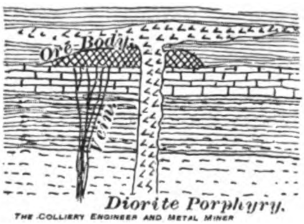


FIG. 167.—FEEDING VEINS, ORE BODY, DIKE, INTRUSIVE SHEET, NEWMAN HILL, RICO, COLORADO.

The ore is iron and copper pyrites. Rhodocrosite appears in the upper part, then zincblende, galena and gray copper appear. Continuing upwards, the ore increases; also the gold and silver contents. Argentite, polybasite and stephanite occur in vein centers, together with horn-silver and native silver. The limestone is often well replaced with ore. The contact ore is a solid mass of pyrites, galena, zincblende and gray copper. The silver contents are from 300 to 800 ounces per ton, and the gold two to nine ounces. The deposits are very uniform.

The *cross vein* matrix is white quartz, enclosing portions of altered country rock. The dip of these veins being nearly flat, a greater fracturing of the shales and

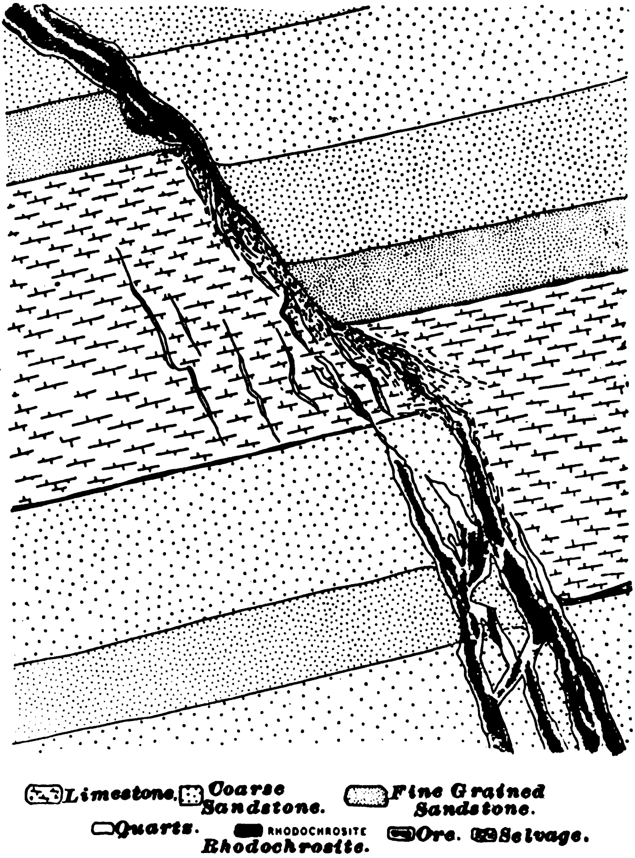


FIG. 168.—VEIN IN FAULT PLANE, NEWMAN HILL, RICO, COLO.

sandstones of the hanging-wall took place, allowing solutions to circulate freely and enclose pieces of wall rock.

A number of fissure veins are said to occur in Dolores Mountain, above Newman Hill, showing the faulting extending through the mountain. Their limitation to the *contact zone* is thus explained; after the fault fissures later movements closed the fissures in the soft argillaceous shales overlying the contact limestone, preventing circulation upwards."

The San Juan region of Colorado takes its name from the San Juan Mountains, a lofty, irregular mountain mass of a northwest trend, composed almost entirely of prodigious flows of lava, emanating from a series of dikes concealed underneath the flows. These horizontal flows have buried under their mass the primitive granite, which is occasionally to be found peeping out from underneath the lava at the bottom of the profound canons, from whose depths we look up at a vertical section of from 2,000 to 3,000 feet of lava, layer upon layer of different colors.

In a general way this great and interesting region may be taken to embrace the counties of San Juan, Hinsdale, Ouray and La Plata, and parts of the counties of Rio Grande, Conejos, Mineral, San Miguel and Dolores.

Among the best known mines of the region are the Silver Lake, Tomboy, Gold King Consolidated and the Campbird. Their fame is due rather to their size and large production than to anything particularly interesting or unusual in the geology of their several ore deposits.

The mineral production of the several counties named, for 1903, was as follows:

San Juan: Gold, $1,710,607; silver, $417,635; lead, $295,280; copper, $388,979. Total, $2,812,501.

Hinsdale: Gold, $16,515; silver, $17,712; lead, $19,-467; copper, $1,490; zinc, $5,724. Total, $60,908.

Ouray: Gold, $2,171,507; silver, $223,069; lead, $141,963; copper, $50,347. Total, $2,536,887.

La Plata: Gold, $140,700; silver, $4,076; lead, $127; copper, $107. Total, $145,011.

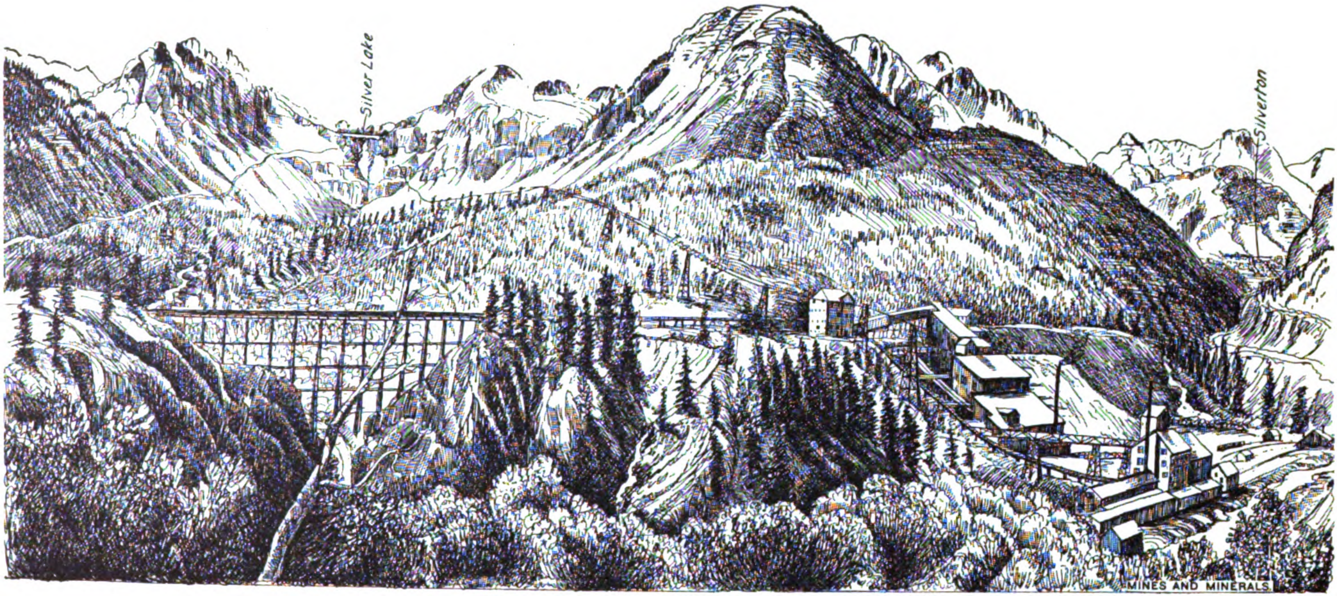
Rio Grande: Gold, $12,939; silver, $1,822; copper, $674. Total, $15,435.

Conejos: Gold, $1,219; silver, $24. Total, $1,243.

Mineral: Gold, $178,960; silver, $859,897; lead, $364,409; copper, $17; zinc, $142,236. Total, $1,545,520.

San Miguel: Gold, $1,176,805; silver, $393,941; lead, $156,947; copper, $61,710. Total, $1,798,403.

Dolores: Gold, $43,262; silver, $55,104; lead, $6,076; copper, $19,533. Total, $123,975.



THE SILVER LAKE MINE AND MILL, SAN JUAN MOUNTAINS, COLORADO.

CHAPTER XXI.

CUSTER COUNTY, COLORADO.

Custer County comprises the Wet Mountain Valley, lying between the Wet Mountains, or Greenhorn Range, on the east and north and the Sangre de Cristo on the west. The Greenhorn Range is a continuation of the Front or Colorado range of Archæan granite, with Mesozoic formations resting against its eastern base. The lofty Sangre de Cristo range is a continuation of the Mosquito or Park range, and its geological structure

FIG. 169.—SILVER CLIFF, OPEN CUT, RACINE BOY MINE.

is similar, viz.: Paleozoic quartzite and limestone, resting upon granite and traversed by dikes of porphyrite and other eruptive rocks.

The principal mines are near Silver Cliff and Rosita, an area of ten miles by six. The underlying granite is broken through and covered by eruptive rocks, consisting of diabase, andesite and rhyolite, which outcrop at Silver Cliff and Rosita. The city of Silver Cliff is on the open plain near a *mesa* ridge, on whose face the silver deposits are developed in the Racine Boy mine. The rock of this

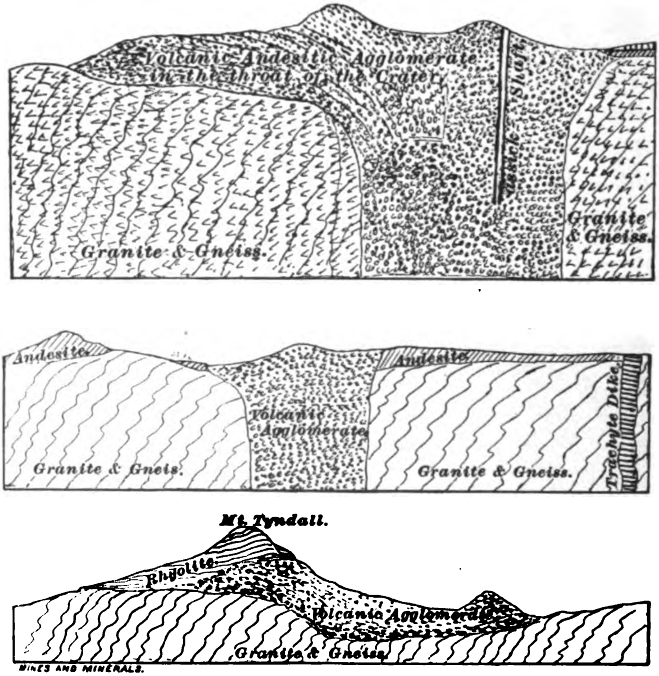


FIG. 170.—SECTIONS OF THE BASSICK VOLCANO.

cliff is a light pinkish rhyolite, showing the laminated fluidal structure peculiar to this kind of lava. A black, glassy variety of rhyolite also occurs. Outcrops of granite are found on the plains between Silver Cliff and Rosita, implying that the rhyolite rests on underlying Archæan.

The Bassick mine and the Bull Domingo, situated near the northern limits of the eruptive rocks, are among the most remarkable mines. The peculiar feature of both these mines is that the ore is found in large bodies with-

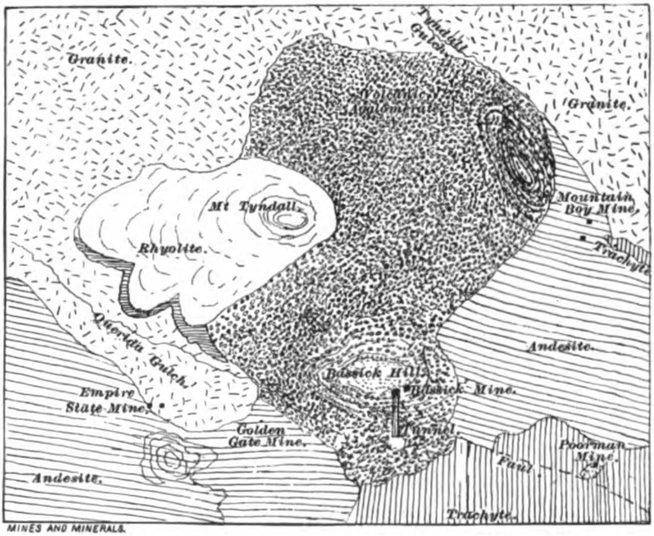


FIG. 171.—GROUND PLAN OF THE BASSICK VOLCANO.

out any definite boundary, forming a coating on irregularly rounded fragments of the adjacent country rock. The country rock of the Bull Domingo mine is a hornblendic gneiss. The ore, principally argentiferous galena, forms a regular semi-crystalline coating from one-eighth to one-fourth inch thick around bowlders and pebbles of rock, and fills the interstices. These pebbles are not in direct contact with one another, but are separated by the metallic coating belonging to each individual pebble. The galena is covered by a second botryoidal coating of a siliceous nature. The deposit is from forty to sixty feet wide, and strikes in a northwesterly direction.

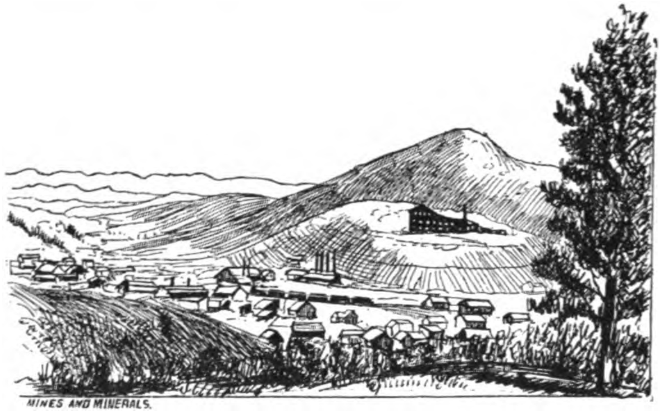


FIG. 172.—BASSICK MINE, TYNDALL MOUNTAIN, QUERIDA, COLORADO.

The Bassick mine occurs in the throat of a volcanic vent, on the eastern edge of the eruptive area. It was an independent eruption of andesite. The shaft is down over 1,400 feet in volcanic agglomerate. This agglomerate consists of bowlders of several kinds of andesites, mingled with Archæan bowlders. The bowlders are rounded by attrition, bedded in gravel and sand derived from the same action. Occasional fragments of charcoal, partially mineralized or entirely unaltered, are found at a depth of eight hundred feet from the surface. The agglomerate fills a typical neck of a volcano below the crater. The irregular oval opening is from twenty to a hundred feet in width. The bowlders or fragments of rock filling this neck or channel vary in size from two feet to the smallest dimensions. They are rarely in contact, while the metallic coatings surrounding them touch one another.

The ore appears as concentric zones about the bowlders and as a replacement of a gravelly matrix. In this

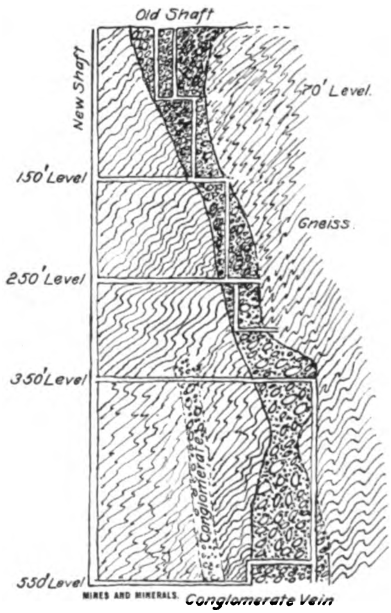


FIG. 173.—BULL DOMINGO MINE, SILVER CLIFF, COLORADO.

metallic coating there is a series of concentric layers, the innermost and thinnest consists of sulphide of lead, antimony, and zinc, assaying sixty ounces silver and one to three ounces gold to the ton. A second coating, lighter in color, contains more lead, silver and gold. The third shell is zincblende, carrying sixty to a hundred ounces silver, fifteen to fifty ounces gold, with a good deal of iron and some copper. The fourth shell is of copper pyrites, carrying good values in gold and silver. These layers or coatings are not always constant or complete, the remaining spaces between the pebbles are filled with kaolin. The entire mass has been permeated by thermal waters, which have decomposed the rock fragments and deposited quartz, opaline, silica and kaolin in abundance. Silicate of zinc, gray copper, free gold and tellurides of gold and silver are also found in this mine in small quantities.

The Racine Boy mine, near Silver Cliff, is an irregular impregnation of the country rock. The Geyser shaft has penetrated 1,100 feet of horizontal breccia and tuff. This shows that a lake existed here, gathering materials from a vent near by. Chloride of silver occurs in the Racine Boy mine. (Plate 3013.)

Some further account of the geology of this region is gained from Mr. Cross, of the United States Geological Survey.

Three miles east of Silver Cliff, and five hundred feet above it, is a compact group of rounded hills, called the Rosita Hills, composed of products from a series of eruptives, overlapping one another upon a knob of granite. The main points of interest in these are: A sequence of eruptions building up the Rosita Hills; the single eruption of Silver Cliff, and periods of decomposition in which the mineral deposition occurred.

The Rosita Hills eruptions came from single volcanic centers, which gave vent to six eruptions. The first three were of andesite lava, next rhyolite, then andesite again, and lastly trachyte. Some of these outbursts were of a quiet nature, others explosive, and one was followed by solfataric action, which is the ordinary history of a vol-

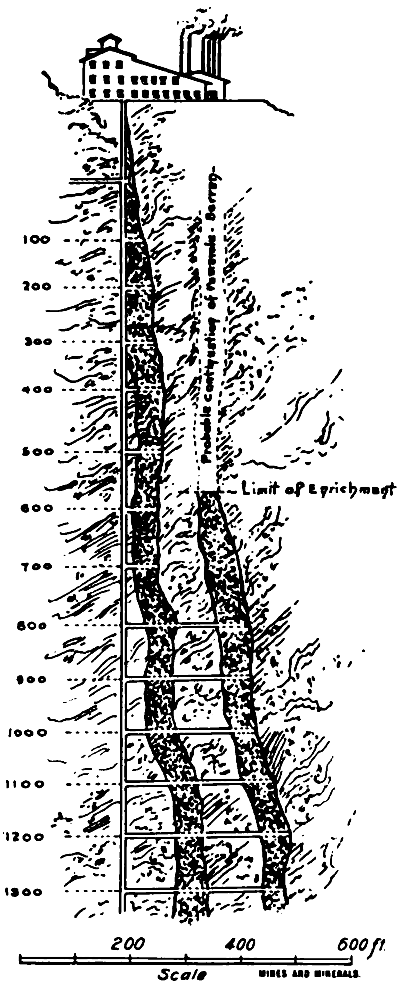


FIG. 174.—ORE SHOOTS OF THE BASSICK.

cano. The first eruptions consisted of hornblende andesite, with breccia and tufa mud flows. This must have built up a cinder cone, partly eroded, before the second eruption, which was of massive rock. The rocks are of a purplish color, to be seen at the town of Rosita on Purple Hill. No exact location of the vents is known.

The second eruption consisted of a holocrystalline, fine-grained, massive rhyolite, with hornblende, augite and biotite, and formed the northern half of the Rosita Hills. The effusion was quiet and through fissures. Being harder than the surrounding rocks, it forms peaks. The biotite andesite is cut by a diorite of plagioclase, orthoclase, augite, magnetite and biotite. This biotite again is traversed by pegmatite veins.

The third eruption was of andesite, forming rounded hills south of Rosita, and differs slightly in composition from the Bunker andesite.

The fourth eruption was of violent nature, occurring twice through numerous vents. The rock is rhyolite from a large number of eruptions of small extent. There were alternations of massive and explosive eruptions. In Wakefield Hill, one mile south of Rosita, is a true vent. There is a mass of rhyolitic agglomerate formed of pumice, kaolinized, with pieces of massive rhyolite and rounded bowlders of granite and gneiss. This agglomerate is cut by massive rhyolite dikes, the channels of which are found on Mount Robinson, Democrat Hill, Knickerbocker Hill, etc. From these vents the lavas spread out over the low ridges surrounding the hills, and are found in remnants much further from the source than any other rock of the series.

The rhyolite eruptions at Silver Cliff are on a much larger scale than at Rosita. Round Mountain represents the source of Silver Cliff lava flow. Beneath the banded rhyolite of the cliff is a zone of round bowlders, with cavities containing ore. These "*eggs,*" or spherulite pitchstones were embedded in a very soft kaolin clay. In other places glassy pitchstone was the matrix. The clay is the result of a decomposition of the pitchstone, consisting of kaolin and opaline silica.

Succeeding the rhyolite came another andesitic eruption through long fissures, penetrating all the older rocks. The rhyolite is cut by these andesite dikes, and surface flows of it rest on the rhyolite. It is a mica-augite-andesite. Dikes of it occur at Rattle Snake Hill. Last, there came true trachyte, by the largest and longest of fissures, and penetrated all previous groups. It was not explosive in character. Game Ridge, near Rosita, represents its outflow, and the dikes extend from Rosita to the west base of the hills.

The mountains built up by the lava were never much larger than now. The changing of the rocks by solfataric action is quite what is found in modern regions. This took place immediately after the rhyolitic eruption; that is, the closing phase of the rhyolitic period of eruption of the volcano.

The rough rock of Democrat Hill is two-thirds quartz and one-third alunite, the original rock structure having been destroyed. In Mount Robinson the crest is due to a dike similarly altered to alunite. The alunite has here been further decomposed and extracted, portions of its alumina remaining in crystals of hydrous alumina, called diaspore.

Since the eruptive period, decomposition and erosion have followed. By decomposition large areas of andesite were bleached by hot waters, charged with various solvents, and the ore deposits are connected with the same.

It is probable that this volcanic area was an outlier, connected with still greater eruptions to the southwest.

Custer county is credited with a production for 1903 as follows: Gold, $82,804; silver, $85,613; lead, $16,409; copper, $6,914. Total, $191,740.

CHAPTER XXII.

TELLER COUNTY, COLORADO.

THE CRIPPLE CREEK MINING DISTRICT.

Exhaustive reports have been made on this interesting and productive region by Messrs. Penrose, Cross and others of the U. S. Geological Survey, and numerous papers have also been written by private individuals. Mr. T. A. Rickard, formerly State Geologist of Colorado,

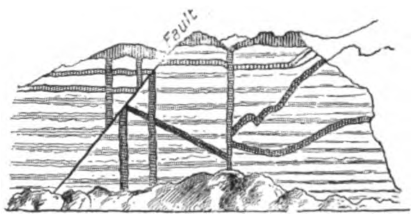


FIG. 175.—DIKES IN VOLCANIC LAYERS OF TUFF.

gives, among others, a graphic description of the Cripple Creek volcano:

The Cripple Creek district occupies a cluster of foothills to the southwest of Pikes' Peak, and is a portion of an extensive, though uneven, plateau, uniting the eastern range of the Rocky Mountains with the Sangre de Cristo. It is a small volcanic area of about twenty square miles amid the granite of the Front Range; and is an outlying portion of a much larger volcanic region, stretching to the

worn surface of the granite and fills the deep basin around a volcanic vent. The breccia has been broken into by several eruptions of phonolite and later still by a series of dikes of basalt and other altered rocks of a highly basic composition. The general eruption is supposed by Cross to have taken place in late Eocene or Miocene Tertiary times.

The granite forming the basal rock of the region is probably of later date than the Archæan. It includes in its mass numerous fragments of schist and quartzite of

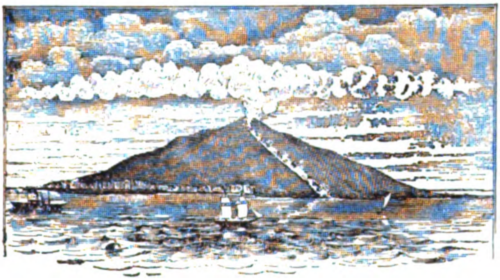


FIG. 177.—ERUPTION OF STROMBOLI VOLCANO.

Algonkian rocks. There are several kinds of granite represented. One is the coarse red granite characteristic of Pikes' Peak, this is penetrated by newer and finer grained granites also of a deep red.

The breccia and tuff consist of consolidated masses of fragmentary material of all the eruptive rocks represented, together with a few fragments of granite, the latter more near the ancient granite surface. Such material would be that which was ejected from an explosive volcano, and after being thrown into the air would, mingled with condensed steam, pour down the sides of the volcano and over the region in the form of mud flows, filling up valleys and overwhelming hills of granite, and generally obliterating the characteristic features of the scenery. (Fig. 177.)

The term breccia is given to the deposits of coarse, and the term tuff to deposits of finer material. Penetrat-

FIG. 178.—PHONOLITE KNOBS, CRIPPLE CREEK.

ing the mass of breccia and extending down into the surrounding granite is an intricate series of dikes, chiefly phonolite. Phonolite is a dull grayish green rock of even texture and sherd-like fracture, composed principally of sanidine, feldspar and nepheline. A peculiar chemical character of the rock is the highly alkaline nature of the

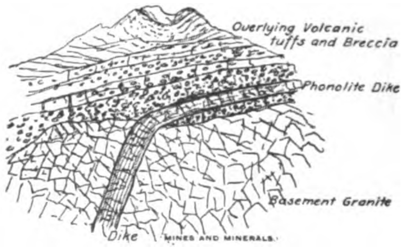


FIG. 179.—PHONOLITE, DEFLECTED DIKE, CRIPPLE CREEK.

minerals composing it. Dikes and sheets of andesite also occur, and finally crossing these rocks and last in eruption are dikes of nepheline basalt with which important ore bodies are associated on Raven Hill and Battle Mountain.

The Cripple Creek district represents the ground floor of a volcano, the superstructure of which has been removed by erosion. The main center of this volcanic crater appears, according to Cross, to have been between Battle Mountain and Bull Hill, in the vicinity of the town of Independence. There were probably more vents than

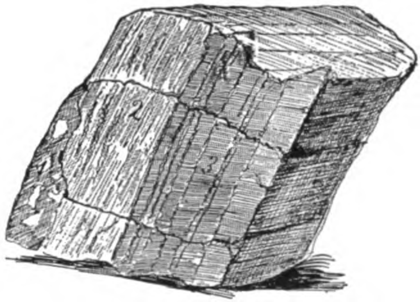


FIG. 180.—SECTION OF THE MOOSE VEIN, CRIPPLE CREEK.

one, and minor vents within the larger vent. One such appears to occur in the massive granite of Squaw Mountain, and another in the Anna Lee mine. These circular orifices are filled with lapilli or fragments of rock between the interstices of which, in the Anna Lee, rich ores have been deposited, somewhat as in the Bassick mine at Rosita.

After the volcanic energies had declined, there followed a long period of smothered activity, evidenced by geysers, hot springs and fumarole or solfataric action, accompanied by steam, hot water, and various gases carrying more or less mineral matter, decomposing the rocks, and depositing the ores and vein matter in any weak place caused by previous disturbance. The gases

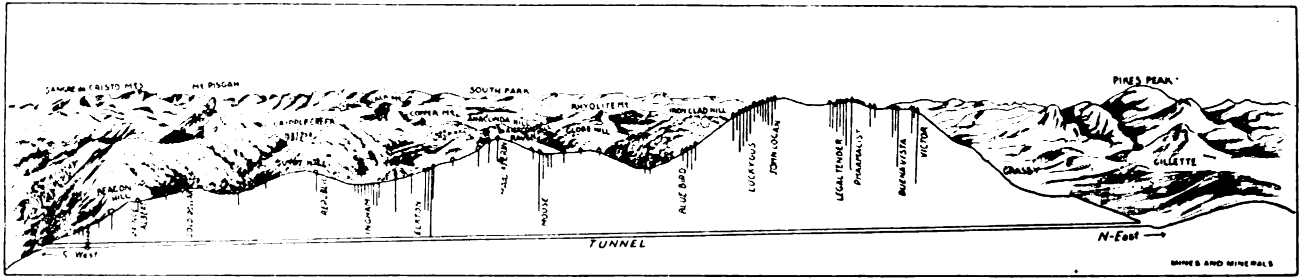


FIG. 181.—PANORAMIC VIEW OF CRIPPLE CREEK, SHOWING PROJECTED STANDARD MINING AND DRAINAGE TUNNEL.

discharged in the solfataric period appear to have been principally sulphuric and hydrofluoric acids.

As regards the ores and veins, the following summary from Mr. Penrose's report, covers the ground:

The ores consist of the country rock, more or less replaced by quartz, with fluorite, silica and kaolin, contain-

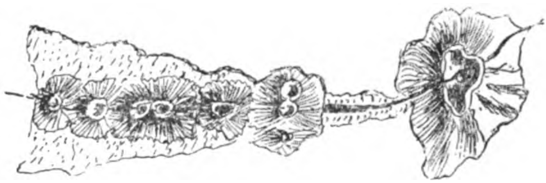


FIG. 182.—VOLCANIC VENTS ALONG A LINE OF FISSURE.

ing iron pyrites and other sulphides, as well as various other minerals in limited quantities. Of late, gray copper has been found at great depth. The gold occurs as free gold, as telluride of gold, and as auriferous pyrites. The free gold is largely derived from the oxidation of the

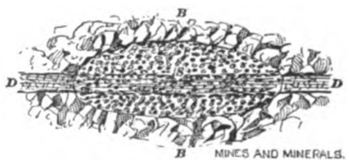


FIG. 183.—ANNA LEE ORE DEPOSIT.

auriferous pyrite and the telluride. The telluride is mainly in the form of calaverite and the silver occurs as a regular constituent of that mineral. After quartz, fluorite is the most common constituent of the ore. Barite also is found in the veins of Globe Hill. The value of the ore shipped may vary from twenty dollars to several thousand dollars per ton.

The veins occur in and near an area of eruptive rocks which overlie and surround a volcanic vent, in fissures formed at a comparatively late date in the history of the district. The fissures are usually represented by one main fracture with numerous subordinate parallel fractures. Two or more main fractures may occur close together. Frequently there is no one especially well de-

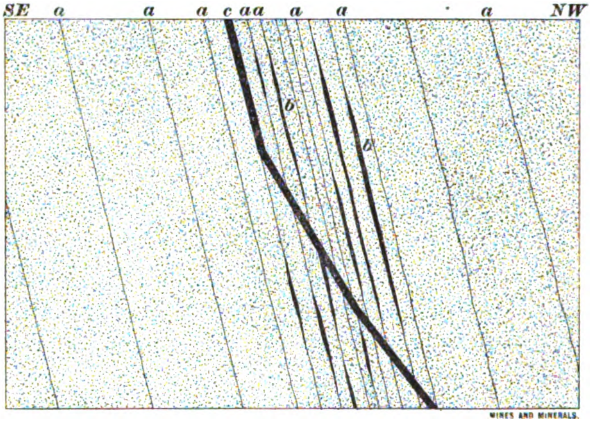


FIG. 184.—VEIN STRUCTURE IN SHEARED ZONE.

fined break, but a number of closely parallel fissures of about equal size. The fissures represent *shearage zones* or fault planes of slight displacement, and are markedly affected by the character of the country rock through which they pass.

The veins blend laterally into the country rock of which they are largely a replacement, and do not all occur as fissures. Some have a certain definite relation to the dikes, because the vein fissures often followed pre-existing dikes. Movements have occurred since the veins were formed. Ore in some cases has been deposited in shrinkage cracks along the contact with the country rock.

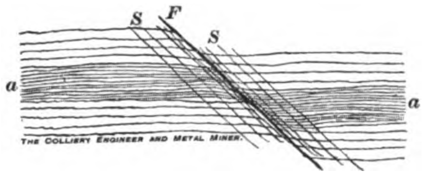


FIG. 185.—SHEARED ZONE AND FAULT, CRIPPLE CREEK.

The gold and associated minerals were derived from the volcanic rocks and to a less extent from the adjacent granite at undetermined depths. The concentration of the ore in veins was due to the influences of agencies gen-

FIG. 186.—FISSURE VEINS, CRIPPLE CREEK.

erated in or near to the volcanic rocks. The vein materials were carried into the fissures in solution and were deposited as a replacement of the country rock after the alteration of the latter had considerably progressed. The deposition of ore in fissures was due to a chemical reaction with other solutions. The localization of ore in chutes is due in some cases to a restricted circulation of ore-bearing solutions guided by the more permeable places along fissures and by transverse fractures.

No single mine is entirely characteristic of the whole district. The veins and ore occurrences, although having much in common, are exceedingly various.

In the C. O. D. mine, in Poverty Gulch, the country rock enclosing the veins is an altered andesite breccia. The ore occupies a well defined fault fissure with well grooved and slickensided walls, and with numerous subordinate cracks on either side of the main fissure, so close

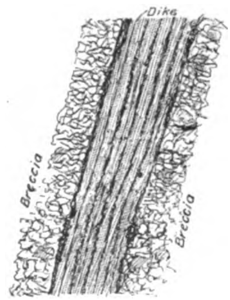


FIG. 187.—SHEARED DIKE, CRIPPLE CREEK.

together as to give a slaty appearance to the zone. Such a structure is typical of a *sheared zone* and is due to intense compression. The ore occurs along the main fissure and lining the subordinate cracks. It consists of country rock impregnated by quartz, purple fluorite, iron pyrites and iron oxides, among which are the crystals of telluride of gold or calaverite. The ore occurs in a well defined chute or chimney representing part of the fissured zone where an unusual amount of ore deposition took place.

The Deer Horn, on Globe Hill, was discovered by the quantities of purple fluorite float found on the surface.

The country rock is breccia, cut by massive rocks and dikes much fractured and altered. The veins are very irregular and devious, and contain the usual minerals. Deep down in the mine are masses of crystallized gypsum, which, with the kaolin and fluorite in the mine, are direct

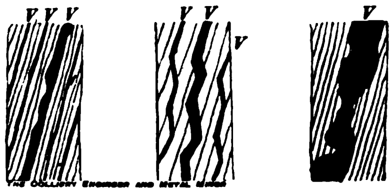


FIG. 188.—CRIPPLE CREEK VEINS.

evidences of a former hot spring or of a solfatara. The mine is in an area of intense disturbance and shattering and reticulated with a network of small veins.

In the Anaconda, on Gold Hill, the ore occurs in a silicified shattered zone following irregularly along the course of an andesite dike, which is itself mineralized.

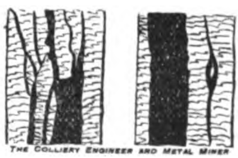


FIG. 189.—CRIPPLE CREEK VEINS.

The Blue Bell contains many fragments of granite and breccia, broken from the walls together with much fluorite stain. A remarkable feature of the mine is the large quantity of water encountered at a shallow depth. Most of the mines of the district were dry until considerable depth was reached, when water often became only too abundant, and necessitated the present Cripple Creek drainage tunnel.

The Caledonia is a true fissure in the southwest granite of Gold Hill.

The Gold Coin is in a shearage zone in the massive granite of Squaw Mountain. The zone is sometimes fif-

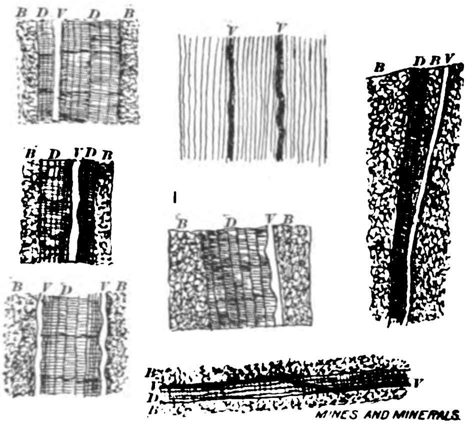


FIG. 190.—GROUPS OF CRIPPLE CREEK VEINS.

teen to thirty feet wide, and carries much telluride ore in the cracks. The ore occurs in well-defined and very continuous chutes.

The Prince Albert is at contact of granite and a phonolite dike. In this mine, also, was an early flow of much water.

On Raven Hill the ores occur in veins in or on the side of dikes of nepheline basalt or phonolite, usually much sheared and cutting the prevailing andesite breccia. Examples are the Raven, Elkton, Thomson, Moose, Doctor and Ingham mines.

The mines on Bull Hill are mostly in veins in the massive eruptive rocks. Others, like the Victor, are in the breccia. The veins occupy well-defined fissures; many of the fissures are entirely independent of dikes. In the Smuggler and Victor and Buena Vista group the vein is

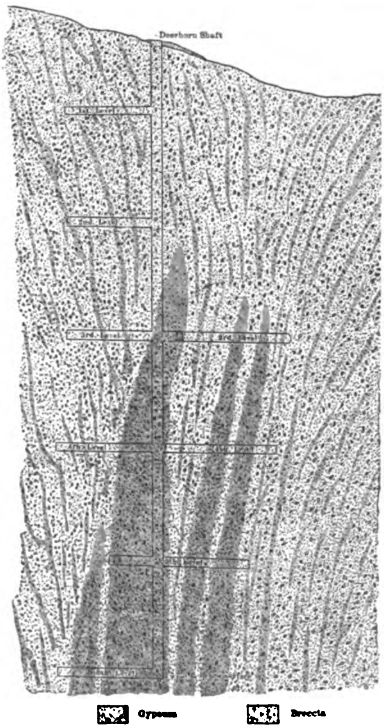


FIG. 191.—PATHWAY OF A FUMAROLE, DEER HORN MINE.

in a zigzag break in hard massive rock, or sometimes in a series of parallel fissures, more or less connected. The country rock is partly massive phonolite, partly breccia.

In the Zenobia mine, on Bull Hill, two veins cross, one faulting the other. On Battle Mountain the veins are both in fissures and fissured zones, cutting the granite or breccia independent of dikes; also in fissured zones, connected with dikes. In some cases they are well-defined bodies of quartz; in others, impregnations or partial

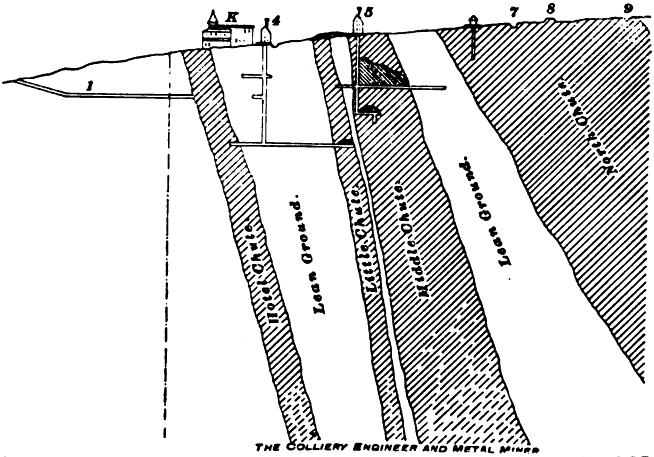


FIG. 192.—ORE SHOOTS IN GOLD COIN MINE, VICTOR, COLO.

replacements of the granite with mineral matter along fissures.

In the Independence the ore is along a fissure or fissured zone, both in breccia and in granite, near either contact with a phonolite dike or in separate fissures in the country alone. Sometimes a vein in close contact with a phonolite dike, leaves it for a space and again returns to it. The ore in the granite occupies a well-defined fissure, with numerous parallel cracks grouped together in a zone of parallel fissuring. The ore is sometimes confined to the rock which has been replaced on either side of a main fissure, or it impregnates the subordinate cracks, giving the ore body a width of from one to fifteen feet.

The ore is due to an impregnation or replacement of the granite along fissures, and blends into the country rock. The ore is the coarse granite from which mica and quartz have been partly or wholly removed, leaving a honeycombed vesicular mass of partially kaolinized red feldspar, in which the cavities have been later filled by secondary quartz, with more or less iron pyrites and a little fluorite, among which are the crystals of telluride of gold, which is often replaced by a pseudomorph of free gold.

The Portland mine is in an area of breccia, intersected by numerous parallel fissures in a shearage zone. A dike passes along this fissured area, and is itself fissured. An interesting feature is the relationship of the different veins to one another and their independence of the dikes; also the manner in which they pass in their course from one formation to another without being affected. Although the mine has descended over one thousand feet there are no signs of any approach to the granite floor of the crater in which it is located. There is nothing in this mine to suggest a secondary enrichment theory. Some sulphides of copper, lead, zinc and antimony have been found in the lowermost workings of some of the mines on Battle Mountain.

The Anna Lee mine, adjacent to the Portland, has its ore body in an oval cylindrical chimney, twelve to fifteen feet wide, dipping vertically along the course of a narrow basalt dike. The ore consists of part of the dike and breccia, reduced to little pebbles or lapilli, cemented together by kaolin, or else the whole mass kaolinized. It seems to represent the neck of a hot spring or fumarole, such as abounded in the district after the subsidence of volcanic activity. The ascending hot vapors kaolinized the feldspathic element of the rock and deposited the metals. "A similar action," says Mr. Penrose, "was doubtless the cause of most of the ore deposits of the district, the only difference being that here the waters rose along one narrow neck or chimney, while in other places they rose along extended fissures and made more or less continuous ore chutes."

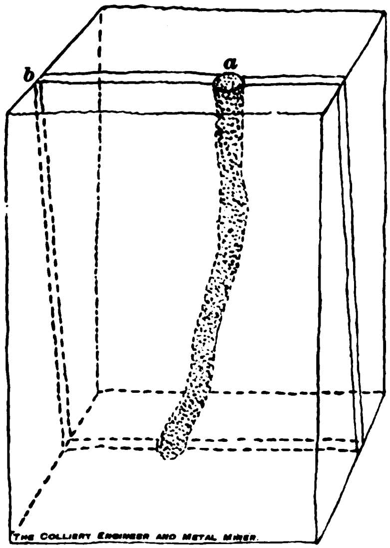


FIG. 193.—ANNA LEE ORE CHIMNEY.

From 900 feet depth downwards the vein or chimney leaves the basalt dike and dips westward about 95°, the vein also losing most of its values after leaving the dike.

Much inconvenience was at one time experienced in the camp by excess of water in some of the deeper mines. This has been partially remedied by the El Paso drainage tunnel, undercutting at some depth a considerable area.

CHAPTER XXIII.

OTHER EXAMPLES OF WESTERN ORE DEPOSITS.

WYOMING.

Wyoming is part prairie and part plateau. The prairie portion is underlaid principally by Mesozoic rocks, which are often upheaved into anticlines and quaquaversals. Such a region is more likely to carry coal and oil deposits than the precious metals.

The main Rocky Mountains die out in the southeastern portion of the state, but granitic rocks appear again east of Laramie, extending north to Laramie Peak, then turning west to Casper Mountain, together with some Paleozoic rocks. In the Wind River and Sweetwater ranges gold ore deposits occur near South Pass and Atlantic Cities, as impregnations of Algonkian schists, which have a great development in this region; also in contact quartz fissure veins between porphyry and schists. The latter is characteristic of Miners' Delight mine, near Atlantic City. This mine has not been worked for some years, but at one time it produced nearly a million in free gold. In the mines at South Pass, of which the Carissa is the most noted, the ore occurs both as an impregnation of a zone of schists and also in quartz lenses and veins. On the surface the ore is free milling, with depth it passes into gold-bearing sulphides, sometimes mingled with free gold. Very large crystals of quartz occur in *"vughs"* in the veins.

In the southern part of the counties of Carbon and Albany, and near the northern boundary of Colorado, is a region known as the Grand Encampment Copper District. Here important veins carrying copper occur in a country rock of Algonkian schists and quartzites, diorite dikes and granite. The ores are, as a rule, copper pyrites or chalcopyrite, though chalcocite, bornite, covellite and their alteration products, malachite, azurite, chrysocolla and the oxides, are found and shipped to the Encampment works. There are two general classes of deposits, one of sulphides, occurring in lenses parallel to and between the stratification planes of the schists, accompanied sometimes by quartz, calcite, siderite and feldspar; the other class contains such rich sulphides as chalcocite, bornite and covellite, with the surface decomposition ores, carbonates and oxides.

At the Charter Oak mine the ore is in granite and diorite. Other ore bodies occur in shattered rock, following the bedding of the quartzite. The Doane-Rambler is the oldest producing mine in the district. It has been systematically developed and has shipped some of the richest ore of the district, car lots averaging as high as 51% copper.

The Ferris-Haggarty mine is the main source of the smelter ore supply. The ore body is outlined for a depth of seven hundred feet on the slope of the vein, a length of two hundred and fifty feet on the second level, and a general width of twenty feet. The ore averages 8% in copper. The mining is economically conducted by levels and upraises from a working tunnel, at the mouth of which are the machinery, buildings and terminal of the tramway. The aerial bucket tramway is deserving of special notice, being one of the longest in the world. Mr.

Henry C. Beeler, State Geologist of Wyoming, says: "The aerial tramway stretches for sixteen miles over a rough country, with high mountains and deep valleys. It was built in seven months and put into successful operation. There are 304 towers to support the cables, the highest being sixty-nine feet high, and sixteen tension stations to take up the slack of the cables, of which there are 293,475 feet, weighing 439,696 pounds. The longest spans are 2,000 and 2,200 feet across the deep cañons. The upper or track cables are stationary, and the lower or traction cables move the buckets. With buckets holding seven hundred pounds of ore each, and moving at an average speed of four miles an hour, 984 tons can be delivered every twenty-four hours in all seasons. The tramway was built in four sections, with three power stations, and storage bins at each of the terminals to provide for stoppages and breakdowns."

In the Medicine Bow Mountains is the Great Rambler mine. Platinum in the form of Sperrylite (arsenide of platinum) has been found in the ores of this mine, associated with covellite and pyrites in granodiorite. Covellite has been found here in greater quantities than ever before known. The geology of the region is somewhat similar to that of the Grand Encampment.

Copper is being developed at Copper Mountain, in Fremont county, in the Big Horn Mountains, in the Laramie Hills and at other places in the state.

SOUTH DAKOTA BLACK HILLS.

The Black Hills were at one time in geological history an elliptical granite island receiving sediments from the surrounding Paleozoic and Mesozoic oceans. These sediments were subsequently uptilted along the flanks of the granite as it arose from its low position into that of an isolated mountain range. The geology is very similar to that of the main Rocky Mountains, of which it is an epitome. The various strata are penetrated by igneous intrusions, among which are those of phonolite, known elsewhere only in the Cripple Creek region of Colorado.

FIG. 194.—A PHONOLITE BUTTE, SOUTH DAKOTA.

Gold and silver-lead deposits occur, also a certain amount of tin in rocks characterized by lepidolite mica and quartz.

Gold occurs in placer deposits, also in Potsdam conglomerates, which are old sea beaches consolidated into rock. Deposits also occur in the Potsdam in the vicinity of porphyry sheets and dikes, consisting of auriferous and oxidized pyrite. The lead silver deposits are very similar to those of Leadville, Colorado.

The Homestake is one of the most noted mines of this region.

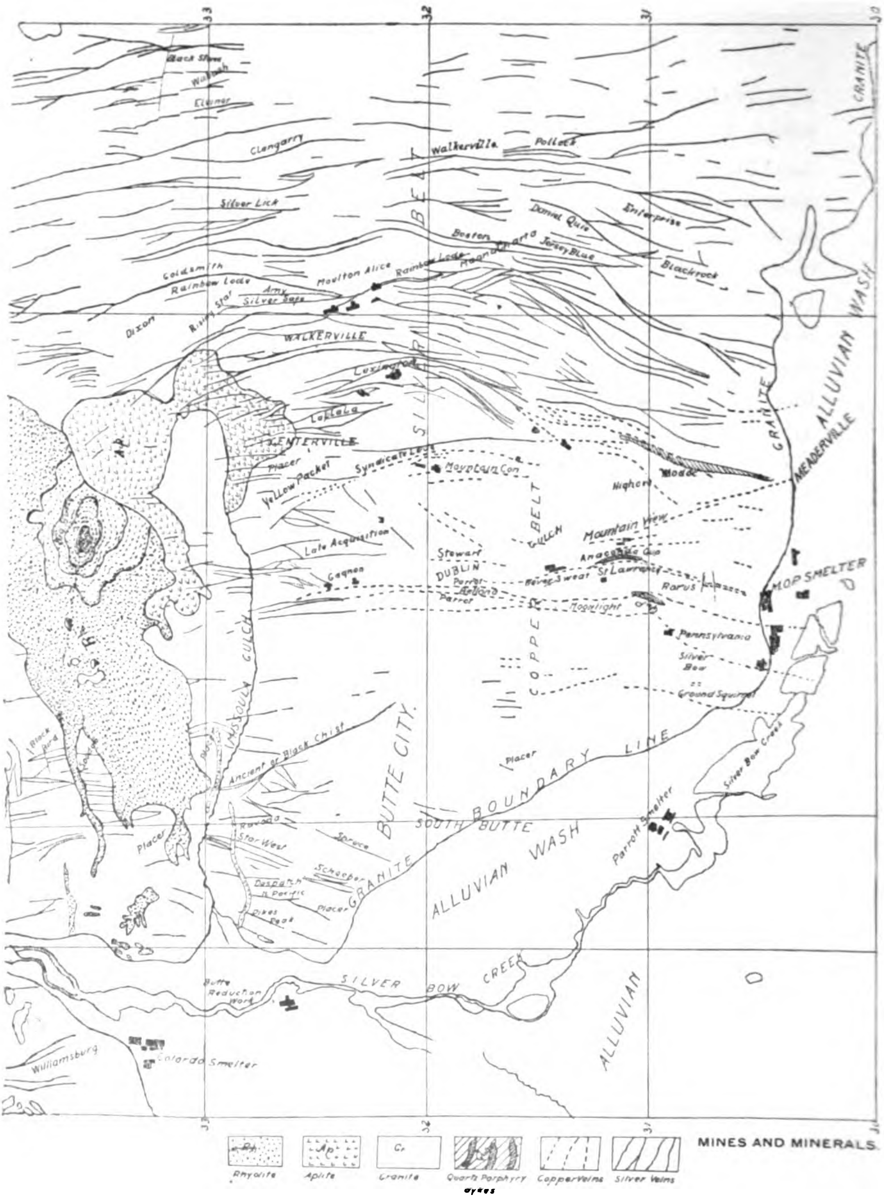
MONTANA.

The geology of Montana is that of a part prairie and part mountainous region, the former underlaid by Mesozoic rocks, the latter by dioritic granite and eruptive rocks, with a prodigious development of Paleozoic rocks.

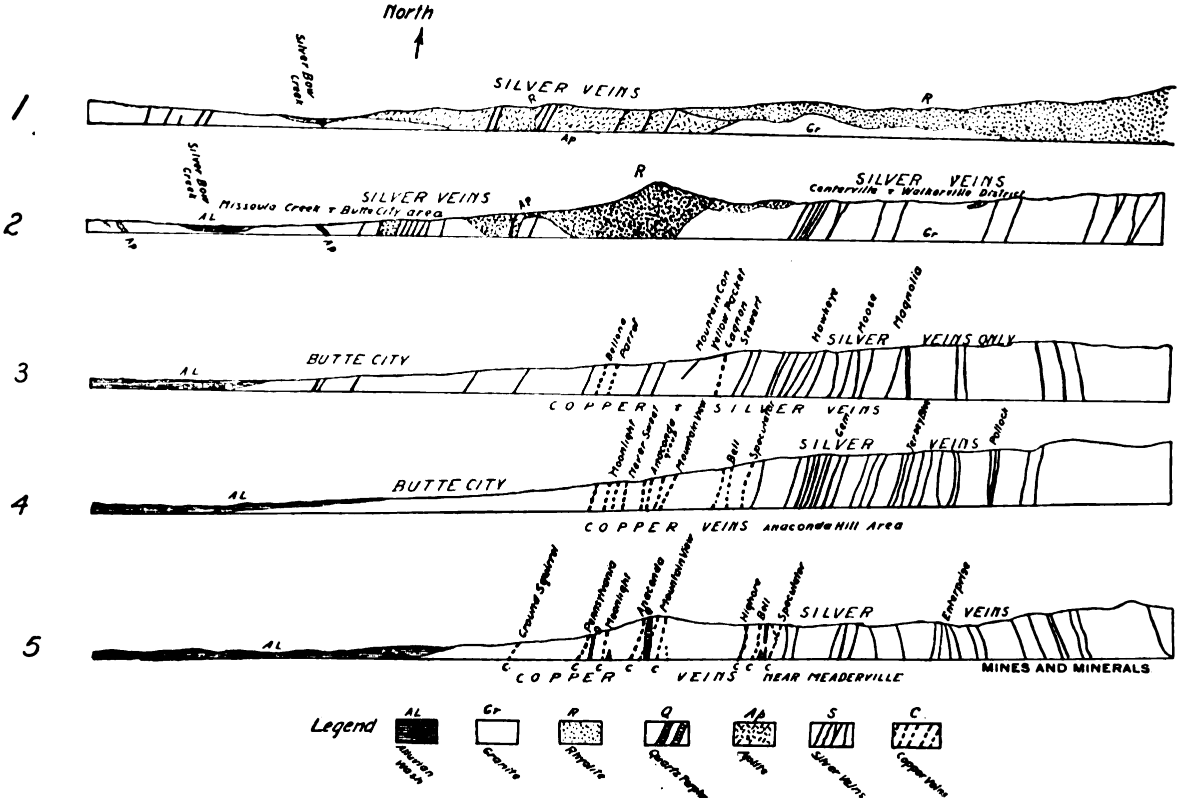
The Butte mining district, so named from a prominent butte of rhyolite in the vicinity, is an area of granite pierced by porphyries and rhyolites. There are two varieties of granite, one very basic, one acidic. There are two distinct mineral-bearing zones of fissure veins, one bearing silver-lead, the other copper. The copper zone is remarkable for what is called a zone of secondary enrichment. The upper four hundred feet was found practically leached of copper, which was deposited below in the form of chalcocite, bornite and other rich copper ores. This zone was two hundred feet thick and one hundred and fifty feet across. Below the zone of enrichment the ores changed again to pyrite. The ores were primarily deposited along a series of small fissures, or *"shearage zones,"* which were gradually replaced, forming wide veins.

The Butte district is to-day the most important copper producing area in the world, the production to 1905 aggregating over two billion pounds, with a total value of about $400,000,000.

The district is one of deep seated igneous rocks, subjected to fracturing at various periods; the resulting fractures in part filled by dikes, in part by veins, but sometimes displacing the veins. It is a region of continued and continuing crustal adjustment. The veins, both copper and silver, belong to three distinct systems. The oldest have an east and west course, such as the Parrot and Anaconda lodes. Another set of fractures displaying the earlier veins is northwest by southeast. A still later northeast set has displaced all the earlier veins. The



MAP OF THE BUTTE MINING REGION, MONTANA.



SECTIONS OF BUTTE MINING REGION, MONTANA.

first two systems, says Mr. H. Weed, are heavily mineralized, the last shows a little ore broken off from earlier deposits and included in the fault debris.

The copper veins were at first worked as silver veins. The surface gossan was soon replaced in depth by oxidized, decomposed copper ores preluding the glance, enargite and bornite ores found below. The copper minerals occur in quartz-pyrite veins of remarkable width, often exceeding a hundred feet. In the great bodies of the upper levels of the Anaconda, rich, solid copper glance occurred for a width of twenty feet.

The copper deposits are replacements formed by waters ascending through mere cracks and attacking and replacing the adjacent rock, particle by particle. In the Leonard mine an ore body is stoped out for one hundred and thirty-five feet in width, consisting of altered granite, sheeted and intersected by a number of small veins, crushed by later movements and impregnated by primary minerals in part replaced by secondary glance. The replacement of inter vein material or altered granite by ore increases with depth. Faulting usually accompanies the rich ores. The miners say, "A dry and tight vein is barren, a wet and crushed one is rich." Increasing depth shows a greater abundance of enargite. The deposits are much influenced by the presence of the quartz porphyry dikes in the vicinity.

IDAHO.

A large portion of this state is covered by the great basaltic overflow of the northwest. This is generally barren of ore until it is broken through by granitic, eruptive and Paleozoic rocks, as in the Sawtooth and other ranges

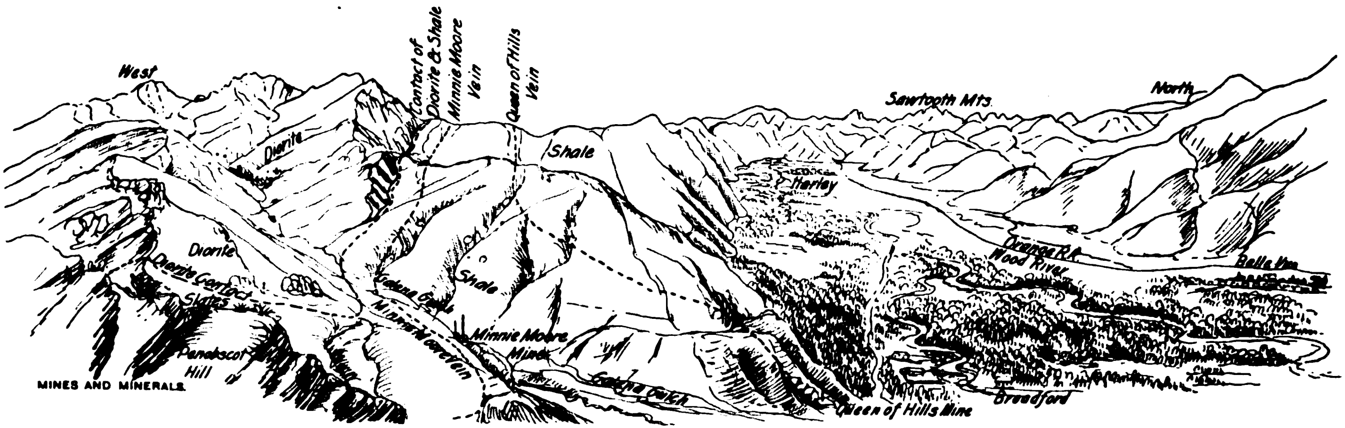


FIG. 195.—THE MINNIE MOORE AND OTHER MINES OF THE WOOD RIVER REGION, IDAHO.

on Wood river. The granite appears to be of late date and eruptive. Tipped up against the granite are enormous bodies of metamorphosed shales and limestones. Vast bodies of diorite and other eruptive rocks have intruded into both the granite and the shales. In such a disturbed region faults abound, and sometimes temporarily suspend mining operations.

The ore bodies near Wood river may be in fissure veins in the granitic rocks, or in the carboniferous limestones, or near the contact of the diorite and the shales or limestones. A typical example of the latter is the Minnie Moore mine at Bellevue.

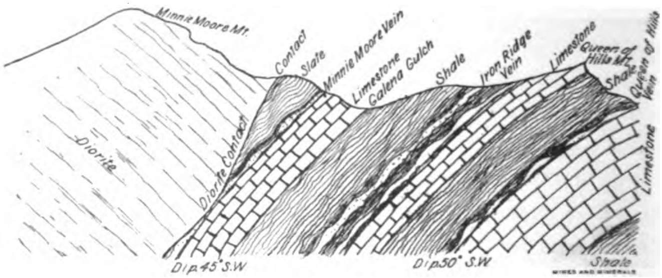


FIG. 196.—ORE DEPOSITS, MINNIE MOORE MINE, IDAHO.

Nearly all the lead-silver ores are very rich in silver. The gold is confined mostly to veins in the granitic rocks, such as the Crœsus mine near Hailey, the ore bodies here lie in what are called composite veins, part fissure and part shearage.

In the Cœur d'Alene region lead-silver deposits occur in shear zones in limestones and quartzite. The ore may occur in large chutes, filling innumerable small fractures in the rocks. In the Wardner district the mines are in quartzite and schists, much folded, faulted and shattered. The portion of Shoshone county, Idaho, known as the

Cœur d'Alene district, is one of the most important lead-silver producing regions of the world. The ore bodies range from five feet to over sixty feet in width, and up to two thousand feet in length. The ore occurs as solid galena in vein-like masses, or as crystals disseminated through the matrix. In the zone of oxidation are lead carbonate and lead-sulphate, associated with zinc and iron pyrites. The gangue is largely siderite, and because of its comparative weight makes concentration somewhat difficult. The Hercules vein presents some interesting features. The outcrop of this vein was described by the state geologist as "an insignificant streak of quartz six

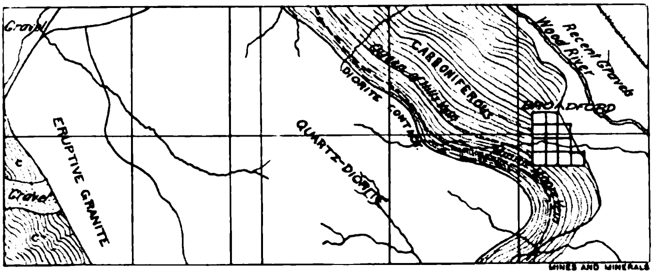


FIG. 197.—MAP OF THE BROADFORD REGION, IDAHO.

inches wide, with spots of iron oxide and lead carbonate, very low grade in lead and silver." At a depth of 1,390 feet from the surface it is a mass of solid galena from five to six feet thick, with a wide zone of low grade concentrating ore. The mass averaged 60% lead and eighty ounces silver to the ton. Above the No. 2 level the ore body shows unusual examples of secondary enrichment. Great *kidneys* of steel galena occur within thick crusts of hard gray carbonate of lead, and an outer crust of snow-white crystallized cerussite, often matted with native wire silver.

FIG. 198.—COMPOSITE VEIN, CROESUS MINE, IDAHO.

The greater part of the ores mined in the district are low grade; they are crushed and concentrated and the concentrates shipped.

UTAH.

The Utah mines are lead-silver, copper and gold. The proportion of gold is small and much less than that of silver. The Wahsatch Mountains, composed of granite, overlaid by Paleozoic sedimentary rocks, are the principal seats of the silver-lead deposits.

The Ontario mine, east of Salt Lake City, is a strong, well-defined fissure vein in quartzite. The vein is from four to twenty-three feet wide and has been followed down continuously for several thousand feet. In the depths of the mine a porphyry dike appears, kaolinized by fumarole action. The ores consist of galena, gray copper, silver glance and blende. Below 400 feet the ore is undecomposed; nearer the surface it is oxidized, the zinc having been removed and the silver occurring as chloride, with some native silver and oxidized copper and lead. The gangue forms 35% of the ore and is of clay and disintegrated quartzite.

The Horn Silver mine at Frisco is in a great contact fissure between a rhyolite hanging and a limestone foot wall. The fissure extends for about two miles, but is only productive at this mine. The ores are horn silver, lead-sulphate, arsenic, antimony and ruby silver. Below the water level, a thousand feet in depth, they are changed to galena.

The Carbonate mine is a fissure vein in hornblende-andesite, filled with pebbles from the walls, cemented by clay and galena. The ore near the surface is oxidized. The cave mines here are replacements of limestone by ore, connected by small ore channels, more or less filled with limonite and oxidized lead ores. The ore is sometimes massive, though the veins show a banded structure, with seams parallel to the walls.

In Bingham cañon bedded veins of oxidized silver-lead occur above, and galena and pyrite below the water level in carboniferous limestones or underlying quartzites, or at contact between the two. The region is much disturbed, faulted and penetrated by intrusive porphyry dikes. A large bed of gold-bearing quartz overlies the lead zone.

In the Tintic district there are three ore belts, from one to three miles long, parallel with the stratification of the vertical blue limestones, and rich in carbonates.

In the Deep Creek region the ore bodies are contact deposits in limestones near igneous rocks, and carry free gold. Large eruptions of granite and andesite occur in the vicinity.

A peculiar occurrence of ore is what is called the Silver-Reef, where native silver, horn-silver and argentite impregnate Triassic sandstones, often replacing organic remains. Above the water level the ore is horn-silver, below it is argentite. The impregnation is supposed to originate from igneous outbreaks in the neighborhood.

Utah produces a number of rare minerals in greater or less quantities, and among these carnotite is found at Richardson and other localities, always in white or gray sandstone, and usually associated with silver and copper ores.

ARIZONA.

Arizona lies partly in the plateau region and partly in the Great Basin. The low-lying portion of the Great Basin is an arid desert, varied by mountains, plateaux and flows of volcanic rock. Cretaceous and Jura-Trias formations largely compose the plateau region. Running southeast to northwest are carboniferous limestones underlaid by granite, gneiss and schists. A great series of ore deposits are ranged along this contact. Vast flows of volcanic rocks cover large areas. The grand cañon of the Colorado exposes a magnificent section from Archæan to Tertiary.

In Maricopa county, Paleozoic and Archæan exposures occur and ore deposits lie along the contact. The ores are silver, lead, zinc and copper. Globe is the principal mining district. Oxidized copper ores occur in carboniferous limestones, associated with eruptive rocks. Copper veins also occur in the eruptive rocks and in sandstones. The Clifton or Copper Mountain deposits lie in a basin, six miles across, of carboniferous limestone and sandstone, resting on granite. In the basin is a mass of porphyry, containing inclusions of limestone. Felsite dikes also abound.

The Bisbee district, in the southern part of Arizona, is in beds of Carboniferous limestone, dipping away from a porphyry intrusion. The ores are in the bedding planes of the limestone. Evidence of solfataric action are abundant. The Copper Queen, Arizona Prince, and Calumet and Arizona are the principal mines. The adjacent district in New Mexico has much in common with those mentioned. Copper occurs at the contact of a felsite dike with limestone and in the dike itself.

Copper basin, twenty miles southwest of Prescott, is a depression in decomposed granite, traversed by porphyry dikes and overlaid by sedimentary conglomerates and sandstones. The granite is traversed by veinlets of copper and the conglomerates are cemented by copper.

About fifty miles south of Gila Bend, in Arizona, is another remarkable basin, evidently the crater of an old volcano. It is surrounded by flows of andesite and masses of diorite. Near the center of the basin is a mountain called Copper Mountain, which is thoroughly impregnated with green copper carbonate. Veins of chalcocite also occur.

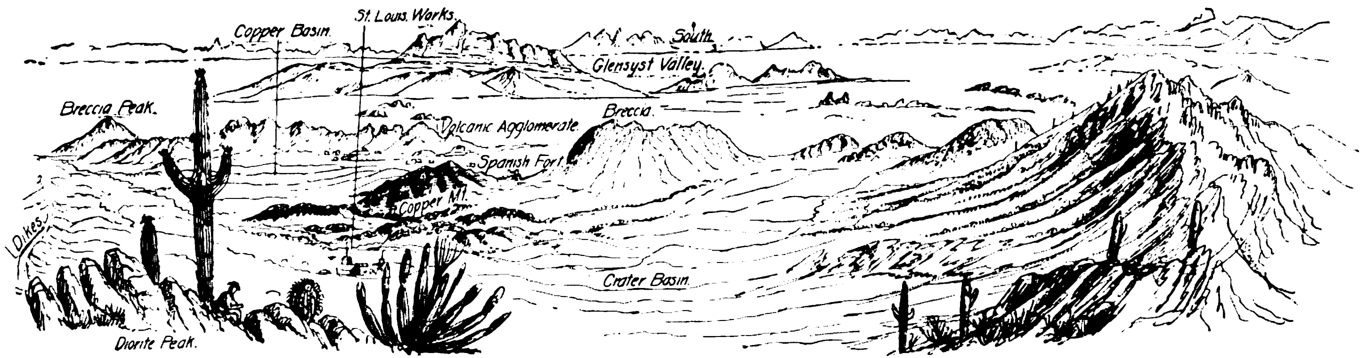


FIG. 199.—COPPER MOUNTAIN BASIN, NEAR GILA BEND, ARIZONA.

The Silver King mine, in Pinal county, is in a central mass or chimney of quartz, with innumerable radiating quartz veinlets, carrying rich silver ores and native silver in a great dike of felsite porphyry, with associated granite, syenite, porphyrite and gneiss of Archæan age.

The region around the hot springs, about fifty miles south of Prescott, is composed largely of evenly bedded schists, containing numerous veins and lenses of quartz, carrying gold ore, parallel with the bedding of the schists, as on Humbug Creek.

On the Santa Maria river gold-bearing veins also occur in schists and gneisses, associated with dikes of aplite, granite and other igneous rocks.

In the Tombstone district, in the southeast, is a great porphyry dike seventy feet wide, cutting folded Paleozoic strata and itself extensively faulted and altered, carrying above the water line, in numerous joints and partings, quartz, with free gold, horn-silver, pyrite, galenite and lead-carbonate. Ore also occurs alongside of the dike and some free gold in the dike. Connected with these fissure veins are bedded deposits in the limestones. In the Toughnut mines the ore occurs in a remarkably regular anticlinal or saddle reef, like those at Bendigo, Australia.

NEVADA.

This state, with the exception of the western border of the Sierras, lies wholly in the Great Basin. A large number of small, isolated ranges are dotted over the surface. These are composed of tilted blocks of granitic rocks, overlaid by Paleozoic strata. Overflows of volcanic rocks are also numerous. The mines are in the tilted blocks.

The ores of Lincoln county, in the southeastern corner of the state, are silver-lead in limestone, or sulphide ores in quartzite and granite. At Pioche is the Raymond-Ely mine in a strong fissure, cutting Cambrian quartzite and overlying limestone associated with an intrusive porphyry dike or sheet. Chutes of ore occur at the contact. The ore deposits are not unlike those on Newman Hill, Colorado, the ore solutions being deflected from their course by a strip of impervious shale overlying the limestone.

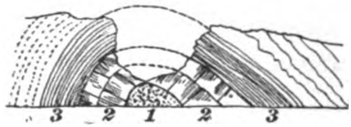


FIG. 200.—TOUGHNUT ANTICLINAL, ARIZONA..

In White Pine county the Humboldt Range is associated with Devonian limestone, in which some of the ore bodies lie in fissures crossing the anticlinal axis, others in beds in the limestone, others at contact of shale and limestone, and, lastly, in irregular vertical and oblique seams across the bedding. The ore is chiefly of silver chloride in a quartz gangue. The ore solutions ascended through the fissure, and, meeting the impervious shale, spread through the limestone.

At Eureka bodies of oxidized lead-silver ores occur in much faulted and fractured Cambrian limestone, associated with eruptive rocks. There are 30,000 feet in thickness of Paleozoic rocks in this region. The ore solutions circulated through the limestone, previously shattered by a great fault, replacing it with bodies of sulphide ores, oxidized to a depth of a thousand feet. The ore bodies were deposited by replacement; all are connected by fissures acting as conduits.

The celebrated Comstock lode is a great fissure vein four miles long, forked into two branches above, along a line of faulting in eruptive rocks of Tertiary age, chiefly andesites. In the center of the fissure the displacement has been about 3,000 feet, shading out at the ends. The ores are high-grade silver ores in quartz. The vein lies on an easterly spur of the Sierras. West of it is Mount Davidson, on the flanks of which are the outcroppings.

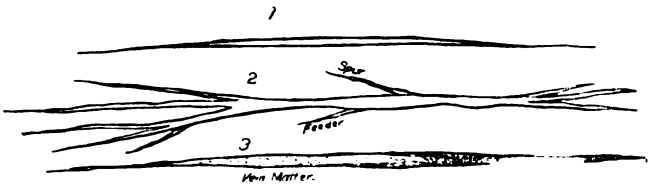


FIG. 201.—ILLUSTRATING FORKING OF VEINS.

The ore and gangue matter ascended from below by solfataric action, associated with fluorine, chlorine and sulphur. The vein filled a fissure between the syenite of Mount Davidson and the late Tertiary eruptive rocks. The vein filling was associated with the eruption of a thin dike of andesite, which forced its way into the contact. The so-called syenite may be a diorite, and the andesites are mostly dacites. An interesting feature in petrography was proven in the examination of the eruptive rocks, viz.: That many of them appearing near the surface shade into forms usually recognized under different names at great depth. Thus andesite, diorite and basalt shade down into diabase; likewise rhyolite into dacite.

The De La Mar mine is located on the border of Utah and Nevada, in some rounded hills composed of beds of quartzite, penetrated by eruptive dikes. The structure is that of the truncated end of a broad anticline. The so-called vein is in zones or shoots of crushed quartzite, adjoining a powerful fracture. Dikes of quartz porphyry are near the mineralized zone, and a black dike of lamprophyre is intimately associated with the mineralized zone and cuts across both the other porphyry dikes and the ore body. All the dikes are intruded prior to the deposition of the ore. The ore is usually only an oxidized quartzite, showing no metallic signs. This jasperoid quartzite has been shattered into fragments and re-cemented by quartz. The gold ore appears to have come principally from telluride minerals. Some lots ran as high as thirty ounces of gold to the ton. The average in the upper workings was $30 to $70 per ton. In the lower levels, where sulphide ores were encountered, the values fell greatly, though the geological conditions continued downwards all the same. So dry is the mine that the walls are covered with an impalpable dust of finely powdered silica from ore discharged down the shoots. Emmons suggested that the barren zone may be followed by one of secondary enrichment, the gold having been leached downward from the surface.

TONOPAH, NEVADA.

The town and mining camp of Tonopah is located in a crater-like hollow, in a somewhat isolated group of rounded volcanic hills. The resemblance to a crater may be more fanciful than real, yet it seems possible that Tonopah, like Cripple Creek, which in some points it resembles, may actually be located upon the seat of an old volcano, for not only are all the surrounding rocks volcanic, but there are in the vicinity numerous volcanic vents, from which the different varieties of lava emanated.

The principal rocks are two or three varieties of andesite and a later cap of rhyolite. That the volcanoes were of explosive type is shown by the brecciated character of some of the lavas, and by heavy intercalated beds of volcanic tuff, composed of comminuted fragments or dust of lava from lava explosions, which fell in a lake near by and became stratified. These stratified tuff beds are most prominently seen in the northern outskirts of the town, where they overlie the ore-bearing andesites and the mineral veins they may contain. In the hills the demarcation between the overlying dark lavas from the underlying beds of light-colored tuff is very conspicuous.

There appears to have been a succession of eruptions, the older ones being of different varieties of andesite, and the later one of rhyolite. It is in the older eruptions, or in certain varieties of andesite, that the fissure veins or mineralized zones occur; and after these zones of broken rock were formed and filled by vein matter and ore, a non-metalliferous eruption of rhyolite occurred, burying the country and its veins and ore deposits. It is only where this cap rock has been removed by erosion, as in the vicinity of the town of Tonopah, that the ore-bearing zones or veins are exposed. Deep down in some of the mines we may locally find the rhyolite lying on top of the eroded veins, filling erosion gulches and depressions in the older and metalliferous formations. After the formation of the so-called veins or mineralized zones, there appears to have been later great disturbances of the region, by which the zones were laterally faulted and dislocated, both above and below ground. One of the most striking features of the region is the evidence of intense fracturing of the rocks, scarcely a foot of rock in the mines, but is fractured, brecciated, or sheared by parallel or cross fractures. The ore deposits themselves occupy zones of replacement of much fractured rock between walls of less broken up material. Faults appear not only on the surface, dislocating the veins and throwing them several feet laterally, as by a horizontal thrust, but deep down in the mines faults of some magnitude occur of a thrust and reverse character, implying great lateral compression and movement.

The underlying rock of the region is probably Silurian limestone. A much-altered hornblende andesite is the oldest rock outcropping in the vicinity, and shows the extreme fracturing mentioned. These fractures became the channels for hot ascending solutions, charged with mineral water, which replaced the zones of broken rock with quartz and ore, thus forming the main so-called fissure veins. After a period of rest and erosion, there was a second eruption of andesite of a different variety, containing pyroxene and biotite as black minerals. Another period of rest and erosion was followed by eruptions of rhyolite and dacite. The quantities of comminuted rock distributed by these explosive eruptions were stratified by the waters of an ancient lake. Finally came eruptions of basalt and intrusions of later dacites and rhyolites. There were no less than four periods of hot-spring action, each following a lava intrusion, and each contributing to the mineralization of the district. The gangue of the veins is a combination of quartz and a variety of orthoclase called valencianite. The primary ores are stephanite and polybasite; secondary from these are horn-silver, ruby and argentite.

The mines are located along certain main and well-defined lines. The mineral-bearing country rock is a rusty oxidized quartzose andesite. The fissures or fractured zones of rock carrying the ore appear to radiate, but are determined by a series of master fractures more or less parallel, but with a tendency to converge in certain directions. The course of the main zones is nearly east and west, with dip north. A secondary set of fissures strikes diagonally towards these in a more north and south direction. These fissured zones usually open up to the surface; a few are found deep down in the mines, apexing towards, but not reaching, the surface, and apparently expanding in size with depth.

The ore near the surface appears as rusty and quartzose matter in a zone of much fractured andesite between walls of more solid andesite. Locally, a very distinct banding of quartz and ore is seen, suggestive of once open cavities. Both ore and quartz form the cementing material between the brecciated fragments of country rock. Down in the mines the ore appears as blackish or grayish stains and bands in the quartz, and the blacker and more discolored the rock the richer it is.

On entering some of the deep mines like the Belmont and Mizpah, the ore-bearing zone consists of a zone of andesite, much broken and sheared, shearage cracks running both parallel to the walls and at right angles to them, across the mineralized zone. Fractures are everywhere, and both on and below the surface the whole region is suggestive of one that has been intensely shaken, dislocated and crushed, both before and after the formation and filling of the vein fissures. Fault planes are very common. At one place in the Valley View property a profound fault appears to have occurred, letting down a block of country for several hundred feet and locally cutting off some of the veins in one direction. An interesting feature in the Mizpah is that the main vein or fissure in the depths of the mine is overlaid by a flow of rhyolite, the steep fissure vein coming right up against and being abruptly cut off by the heavy horizontal sheet or roof of rhyolite. At the junction of the two formations there is a body of ore following the contact of the rhyolite, with the underlying vein-fissured and eroded andesite. The mines are exceedingly dry, and well developed. Timbers are but little used, except at the stations and shafts, which are models of neatness and good workmanship. The workings of the several mines, which are said to amount to ten miles in all, are so connected that miners can, if need be, work through each other's workings, and in case of accident there are abundant outlets.

The Tonopah Mining Company, of Nevada, and the Belmont are conspicuous properties. The former includes the Mizpah and Valley View veins. The Valley View vein is in parts and for quite a distance from forty to fifty feet wide, carrying ore from $30 to $60 per ton. The workings are down 700 feet and the vein has been followed for 2,000 feet in length with an average of 15 feet in width.

The Montana Tonopah is located on one of the main group of veins parallel to the Mizpah. The shaft goes down 670 feet, passing through the overlying rhyolite cap, it cuts the vein at a depth of 360 feet. The vein dips steeply north. The strike is northeast and southwest. Five important veins are cut in the workings of this mine at an average distance apart of about 100 feet. The two principal are the McDonald and the South vein, the former from 8 to 16 feet wide, the latter about 8 feet wide, with a dip north of about 40 degrees. The south vein shows well the compression and disturbance to which the area has been subjected by being faulted by a nearly horizontal thrust and reverse fault. The dislocation of the vein is about 40 feet; the fractured limb of the vein is recovered toward the hanging wall side. An interesting feature is the banded character of the vein, the bands showing in crenated or crumpled lines of dark mineral on white quartz near the foot wall. The ore is stephanite or brittle silver, running as high in places as 70 ounces gold and 2,000 ounces in silver, the average being an ounce of gold to 100 ounces of silver. Polybasite and argentite are higher in silver, but carry little or no gold; ruby silver is also not uncommon. A little gouge occurs between the vein and the walls. The walls are at times also impregnated with ore, but too low grade to be worked profitably. A convergence is observed, both in strike and dip in these veins, and it is thought that at a depth of less than a thousand feet they may come together to form one large ore body. All the ore hitherto taken out of this promising mine has been in the course of development, and there are apparently almost inexhaustible reserves.

The parallel McDonald vein is similar in character to the south vein. An interesting feature in part of this mine is the bulging down of the rhyolite cap rock, as in the Mizpah, on top of the andesite and its truncated veins. Unlike the same occurrence at the Mizpah, there is no sign here of ore at the contact. It appears in this mine to be filling a local, once surface gulch of erosion in the underlying formations. The ores of the Montana Tonopah differ somewhat from those of the Mizpah in containing more pyrite and sulphides. The walls throughout the mine are intensely fractured. Little faults occur here and there, filled with quartz, picturing in miniature the greater thrust faults of the district. The average value of the ore of this mine exceeds $100. Stoping is mostly on the south vein, where the main fault occurs, and where the ore vein averages from 8 to 10 feet from wall to wall.

The Midway property is to the north of the others. There is a parallel system of veins here, striking east and west with a nearly vertical dip, but with a tendency to dip south, contrary to the prevailing dip of the other veins. There appear to be four main veins, one is eight feet wide, separated by a hundred feet from the next, which is four feet wide, and that by another hundred feet from one five feet wide, and that again from one four feet wide by an interval of fifty feet. The same much fractured condition of the walls is observed. Slips or faults are numerous and their prevailing dip is 45 degrees and to the north. Slickensides, breccia and gouge are abundant as signs of motion. The ore averages $60, with a proportion of 1 ounce of gold to 100 ounces of silver. This vein is supposed to be an extension of the Mizpah, and if so, it would prove that vein for a length of 4,000 feet.

Endeavors have been made to follow the strike and extension of these main veins further north in the flat valley beyond the town, and many trial shafts have been put down. The difficulty encountered here is from a thick overlying lake bed of horizontally stratified tuff, which covers up all the lower formations.

There are several important outlying districts, such as the Lone Mountain, Gold Hill and Gold Field districts, which show great promise. It may be said that the whole country for two hundred miles between Tonopah and Reno, on the Central Pacific, shows signs and geological conditions favorable to ore occurrence. Apart from the mines, such as those at Tonopah, the Comstock, and the Candelaria district, there are the surface signs of mineralization, such as the occurrence of andesites, rhyolites, diorites and other volcanic rocks and eruptions. The region is one of intense past vulcanicity, whose dying forces are still seen in the fumaroles of Sulphur Bank and Steamboat Springs. Comparatively recent craters also occur with breached cones, and lava flows of olivine basalt. In the sedimentary rocks and limestones, such as those at Lone Mountain, there is evidence of intense metamorphic action, and at Lone Mountain metamorphosed limestones occur intruded into by sheets of igneous porphyries, as at Leadville, Colorado, carrying the same class of ores as in that noted region.

GOLDFIELD, NEVADA.

(By J. E. Spurr, U. S. Survey.)

Goldfield Camp lies 23 miles south of Tonopah.

It was located in 1903, and in January and February of 1904 rich finds were made on Columbia Mountain, and by the end of that year there were over 6,000 people in the vicinity, and over two million dollars worth of ore, principally gold, had been shipped, most of the shipments being in the last five or six months of the year.

The district is bounded on the west, in part by a lava-capped mesa, the erosion of which has laid bare the underlying gold-bearing rock. The auriferous region is characterized by numerous low, irregular ridges standing out above the lower and more nearly level surface. These ridges owe their origin to hard reefs of quartz, forming their crests. In these the gold-bearing deposits are found.

Columbia Mountain is the most prominent of these ridges. Near its south end the rock is largely Alaskite (an igneous rock consisting of quartz and feldspar). Pure quartz veins of similar origin also occur. These Alaskite rocks are intrusive into a dark silicious jasperoid rock. On the north end of the mountain the rock is a very much altered rhyolite, enclosing broad masses of white to purplish and reddish, cherty quartz, extending irregularly in a northerly direction. This quartz is simply a highly silicified rhyolite. The silicified areas have ill-defined walls and the highly mineralized portions which they enclose are very irregular. The area of the known ore bodies has rapidly spread since the first discovery so far beyond Columbia Mountain that the values are now found over an area of over six miles square, including the mines of the Columbia, Diamondfields and Jumbo groups. The rocks in this mineralized area are entirely volcanic, consisting of rhyolites, rhyolite tuffs, andesites and basalts of probably Tertiary age. Basalt is rare. These rocks probably correspond to those at Tonopah.

At Goldfield the ores occur in both rhyolites and andesites, showing that mineralization occurred subsequent to the eruption of both lavas. At Gold Mountain the deposition of the ores followed the eruption of the rhyolites and at Tonopah the eruption of the earlier dacite rhyolites was succeeded by a period of mineralization which produced irregular veins that frequently carry a larger proportion of gold than the locally more important veins formed after the eruption of the early andesite, therefore possibly the Goldfield deposits are identical in origin with the later series of veins at Tonopah.

There are in places at Tonopah mineralized quartz reefs in rhyolite tuffs that have the same peculiar characteristics as the tuffs of the Goldfield reefs and assays of these Tonopah deposits have shown a moderate amount of gold and no silver.

At Goldfield the so-called veins are not well defined. The outcrops of the quartz bodies for the most part are irregular, straggling, branching and apt to disappear suddenly. There seems to be a general tendency to elongate in a northerly direction. The outcrops may even be nearly circular or crescentic and frequently they are roughly lenticular and intermittent. The quartz is hard and jaspery, due to the silicification of the volcanic rock in which it occurs. The silicification and accompanying mineralization was the work of hot springs and these irregular reefs represent the horizontal columns of hot water. Had the rocks been strongly fractured we should have had veins like those of the early andesite at Tonopah which were due to hot-spring action. At Goldfield the lack of such fractures resulted in this curious and rather unusual type of deposit. The quartz reefs will probably extend deeper vertically than horizontally in the nature of rough columns or pipes.

Although showing disseminated pyrite, the greater part of these jaspery quartz reefs contains little or no gold. The iron pyrite is probably indigenous, i. e., the iron sulphide has been formed by the action of sulphur contained in the hot spring waters upon the iron silicates contained in the hornblende and biotite. Hence there is no gold.

Within some of these barren reefs of silicified volcanic rocks at Goldfield prospectors have sometimes discovered portions containing considerable gold. Such portions are usually lenticular or irregular like the main quartz reefs and are not easily distinguishable from the barren quartz except by panning or assaying, but it seems probable that these shoots are the real ore deposits and that the mass of the reef constitutes merely a silicious jacket, such as often surrounds ore bodies. While the silicious casing may be 25 or 30 feet wide, the gold-bearing portion may be only one or two feet. On exploitation this is seen to have a definite channel-like shape, often more irregular than that of the whole outcropping reef. These pay shoots probably represent the main channels of the hot water circulation, while the silicious casings are the result of water soaking through the adjacent rock. The ores are often very high grade, for instance a shipment of 14¼ tons from the Sandstorm (Kendall claim) worked in a stamp mill, yielding $45,783 net, while the tailings still contained about $1,000 to the ton. From the McKee-Bowes lease on the Jumbo $600,000 was taken out in five months from a space of 100 feet horizontally and 200 feet vertically on the shoot. The whole production of the camp has been from ore roughly estimated as averaging $200 to $300 per ton or more. The values are all in gold. Silver is practically absent or limited to 1 to 3 ounces. Most of the ore extracted has been oxidized. The ores are mixed sulphides (iron pyrites) and oxides up to the surface. The oxidized material following the cracks and seams is usually several times as rich as the unoxidized portion. The irregular spongy nature of the free gold particles in such oxidized material proves that the gold has been dissolved and redeposited in a concentrated form during the process of oxidation. Iron sulphate derived from the oxidation of the pyrites is the probable agent. Other sulphates, such as alum and gypsum, are abundant. These oxidized ores are screened, the finest being shipped and the coarse quartz rejected.

As the water level for this country is high, water being met in shafts at 150 to 200 feet, it is plain that this oxidized ore is only a temporary supply. In the Combination and Florence mines sulphide ores have been found below the oxidized zone in a dark gray copper-bearing mineral, which may be tetrahedrite. Tellurium is also present. Therefore the sulphide ores may also prove very rich. It appears probable that the rich oxidized ores owe their richness not primarily to the concentration during oxidation, but to the existence of shoots of rich antecedent sulphide ores.

Some of these sulphides are purely of primary origin, others were formed subsequent to the main silicification of the reef as in the Combination mine. Here the rich auriferous sulphides have formed in a breccia zone in the silicified barren reefs and occur as coatings on the fragments of the breccia. The presence of elements like arsenic antimony and tellurium in the subsequent sulphide ores suggests a deep-seated origin. In the January mine bismuth also occurs. Barite is not uncommon.

Indications are favorable to the continuance of high or good grade of ore down to considerable depths. There is not, however, continuous regularity in the ore shoots whether sulphide or oxide. They are curving, irregular and often lenticular, but it may happen that below a shoot, which has come to an end, another shoot may be found occupying a slightly different relative position or even overlapping the first. Similarly the main quartz masses as a whole can be expected to show little regularity in depth. They may increase in size or diminish or even disappear, at least temporarily.

WASHINGTON.

The geology of the state of Washington is that of mountain, steep plateau and lake bed plains, overlaid by vast flows of lava. The Rocky Mountain system appears in eastern Washington, affording considerable ore deposits in granite and gneiss. West of the granite is a plateau country, composed of the deposits of great fresh water lakes, flooded by equally extensive flows of lava. Still further west the Cascades form the central divide of the state. The rocks are granites, flanked by Paleozoic, Mesozoic and metamorphic strata upheaved before the Cretaceous. There are vast developments of igneous rocks, with one or two lofty volcanic cones, such as Mount Rainier. The region of the high mountains has been much glaciated, and living glaciers still exist. Around the shores of Lake Chelan, Archean gneisses and schists contain many fissure veins, carrying gold, silver and copper, and locally, deposits of molybdenum.

Typical of the Cascade region we may take the Monte Cristo district, as described by J. E. Spurr:

The magnificent scenery of this wild region of precipitous mountains and living glaciers is largely due to the geological structure and the existence of numerous systems of joints and fissures, which also have much to do with the occurrence and deposition of the ores. The prevailing country rocks are tonalite, a rock allied to andesite, and andesite, upon which lie Tertiary lake deposits, barren of ore. The ores are classified into two zones: 1. Surface ore zone of zincblende, galena and copper pyrites, with values in gold and silver; 2. A deeper zone, principally of arsenopyrite. The surface

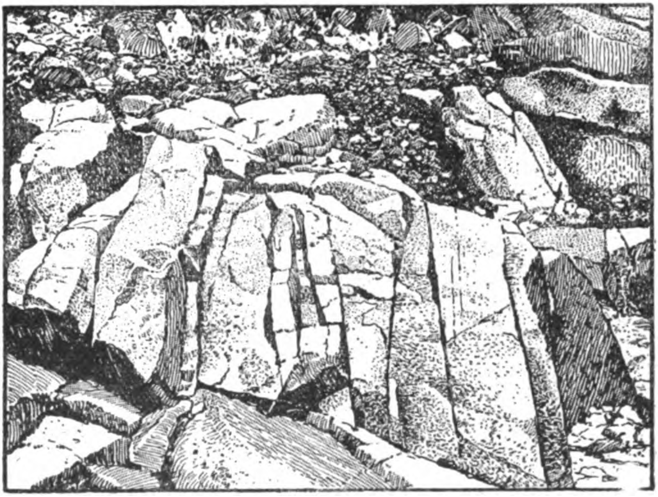


FIG. 202.—JOINTED GRANITE FAVORABLE TO ORE DEPOSITION, WASHINGTON.

zone shows evidence of deposition of ore up to the present day. Mineralization occurs along joints, bedding planes and at contact of tonalite and serpentine. Various kinds of joints are described, including imbrication of veinlets and strain zones. The straightest veins are the richest, because the fissure so formed is a master fissure, controlling the circulation. The ores were deposited by gradual replacement of the country rock along lines of fracture and crushing and near the surface along open cracks, by underground waters carrying down solutions from above. The ores of the upper sulphide zone were formed by surface waters, within the general period of the present climate and topography. The deposition of ore is doubtless actually going on now. The lower sul-

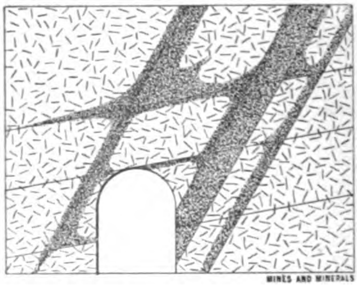


FIG. 203.—MINERALIZATION ALONG JOINTS BY DESCENDING WATERS, MONTE CRISTO MINE, WASHINGTON.

phide zone was deposited later than the upper, also by descending waters.

The region is one of great precipitation, so that all the rocks from the surface downward are heavily charged with downward-moving waters, descending through the joint planes. Both ores and gangue were derived from elements of the tonalites and andesites.

Mr. C. E. Bogardus, of Seattle, says: The country is still in a state of prospect. There are miles and miles of ground that no man has been over. The fir and pine forests are like an African jungle, and the mountains are very precipitous. The trees are large and close together; this, with a heavy undergrowth and fallen logs lying criss-cross, makes travel hard and slow, and no ledges can be found except where nature has opened them up by mountain streams.

The state is mineralized nearly the entire length of the Cascade Mountains, and in the northern part the mineral belt extends east to Idaho. In the northeast corner of the state are large deposits of lead-silver ores, carrying some zinc. In Okanogan County are a variety of ores. There is free milling gold, galena and a zone of rich chlorides. The chlorides are in a limestone belt. The gold occurs in slate and porphyry. St. Lelar, Bridge Creek, Horseshoe Basin, are all in a group. They are silver camps. To the south is a gold district in schists. In the Besleslin, Niger Creek and Swark districts free gold occurs in quartz and talc, with pyrites, both arsenical and chalcopyrite. The veins are large or else the ore occurs in pockets. The average is not high grade. The Snoqualmie district, about seventy miles from Seattle, has some high-grade galena and copper. The walls of the veins are granite and quartzite, with some porphyry. The Cascade district is at the head of the river of that name. The formation of the ore deposits is about the same as that in the southern part of the state. Some good galena, gold and copper are found.

The state of Washington is badly broken up, the strata dip at all angles and many large slides occur.

OREGON.

The geology of this state is very similar to that of Washington, as well as to the lava-covered portion of Idaho. In Baker County there are gold placers and gold-bearing quartz veins. At Port Orford, on the sea coast, the ocean, battering on the cliff of gravel, has carried from it and distributed along the shore quantities of gold-bearing gravel, associated with *black sand*. Another gold field is situated in the southern part of the state, in Jackson and Josephine Counties. It is an extension of the gold belt of California. A third auriferous region is that of the Calapooia Mountains, extending northward toward the Santiam Rim, and centering in the Bohemia mine. Here the gold and silver appears in veins in Tertiary andesites and basalts. A fourth mineral-bearing area is in the Puebla Mountains, in the extreme southeastern part of the state.

The most important gold field of Oregon is that of the Blue Mountains, one hundred and thirty miles west

FIG. 204.—LAVA BEDS OF THE SNAKE RIVER.

of the Snake River. The geology consists of cores of older rocks, surrounded by floods of Neocene lavas, rhyolites, andesites and basalts. The sedimentary beds associated with the ores are principally argillites or slates of Carboniferous age, and many of the veins are found in these or at contact with slates and grano-diorite intrusions, as in the Elkhorn district. Some, like those of the Seven Devils district, occur at contact of limestone and diorite. Again, others occur in quartz veins in diorite close to the argillite contact. The geology appears very like that on Wood River, Idaho. Gold, silver, copper and many other minerals occur in these Oregon mining districts.

CALIFORNIA.

Central California has the Sierras on the east, the great Sacramento Valley in the middle, and the Coast Range on the west. These mountains continue north beyond the boundaries of the state and merge into the Cascade Range. In the south are the San Diego Ranges and portions of the great Yuma Desert.

The Sierras consist of granite and gneiss, with a quantity of slates and eruptives. On the flanks Jurassic, Carboniferous and Cretaceous representatives are

FIG. 206.—FISSURE VEIN MOTHER VEIN, CALIFORNIA.

also present. On the western slopes are great beds of auriferous gravels, covered in many cases by basaltic lava. The Coast Range consists of Cretaceous and Tertiary rocks, considerably folded and metamorphosed, and displaying great outbreaks of andesite and basait. The Sierras, as well as the Coast Range, contain many quartz veins carrying gold. In the slates are numerous lenses of quartz, as well as fissure veins, carrying gold.

The remarkable gold vein called the "Mother Lode" extends from Mount Ophir, in Mariposa County, to Mokelumne Hill, in Calaveras County, or over seventy miles. It outcrops as a white wall of quartz from six to sixty feet thick. It is a lineal succession of numerous large and small quartz veins, running parallel with the strike. The fissures were formed by faulting in steeply-dipping strata. Serpentine is a very characteristic wall rock-with diabase, diorite and granite.

Nevada County has been a great producer of gold. The important veins and mines are nearly all situated in the neighborhood of Grass Valley.

Among the richest quartz mines of California are those of Bodie district, in Mono County. Bodie Mountain is an isolated mass of trachytic porphyry, with its summit 9,500 feet above sea level. The whole region not long ago was a scene of eruptions. In Mono Lake, twelve miles from Bodie, traces of these ancient fires still exist, as is evidenced by the escaping jets of hot vapors and numerous boiling fountains occupying the center of the lake. The mountain contains some sixteen quartz veins, which on the surface are hard, compact chalcedonic quartz, sterile of metal and unpromising for mining exploration. At fifty feet they lose these characteristics, become softer and the quartz more friable. The compact chalcedonic portion, greatly diminished in bulk, forms now a lining upon one or both sides of the vein, more rarely a seam of varying width in the center of the vein. Horses of adjacent porphyry occur, diminishing the vein, which beyond assumes the largest proportions. The metallic contents, which are invisible to the naked eye, are found dis-

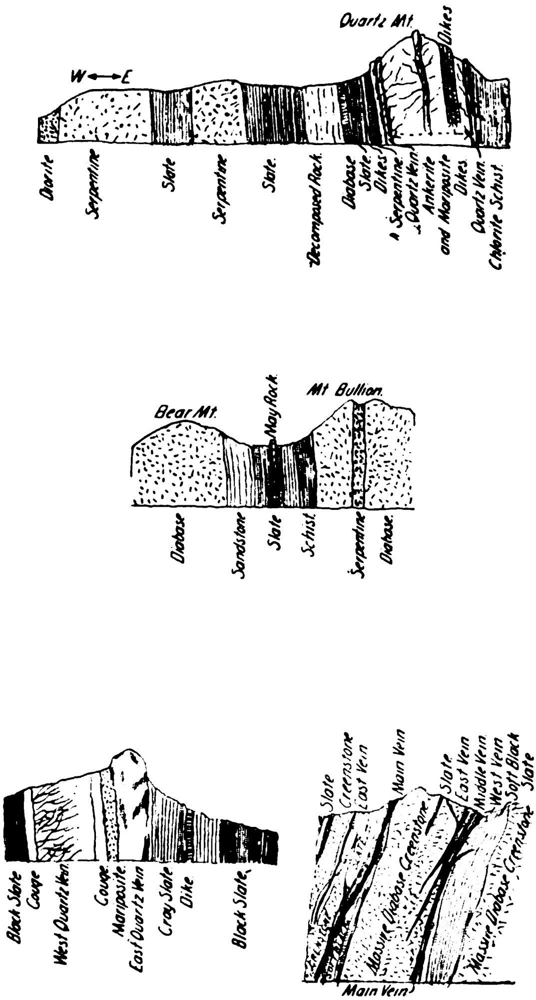


FIG. 206.—SECTIONS OF THE MOTHER VEIN OF CALIFORNIA.

tributed in dark-colored stains, parallel to the surface of the quartz. Magnetic iron ore is found in minute particles, but there is a remarkable absence of metallic sulphides. Blake observes that the Bodie veinstone is formed in layers or coats, one over the other, like sheets of paper, with their seams or openings between, which shows that the veins were deposited gradually in the fissures by thermal springs.

Cinnabar occurs at many localities along the Coast Range, associated with quartz, calcite, dolomite in shattered metamorphic rocks, with diabase, basalt, diorite and serpentine. Eruptive rocks, either of ryholite or basalt, are usually not far distant from the deposits, and doubtless had much to do in stimulating the ore solutions.

The principal cinnabar mines are at New Idria and New Almaden, in the Coast Range, and in some localities further north. Clear Lake, a cinnabar district, is at the end of a basaltic region, abounding in volcanic caves, sulphur and borax springs. Cinnabar appears to saturate porous rock. At Sulphur Bank the ore occurs in the lower portion of decomposed rock, and here both cinnabar and other ores are in process of deposition along the throats of fumaroles.

Tin occurs locally in small quantities at Temescal, in Southern California, and in small veins in the granite of the Temescal Mountains.

BRITISH COLUMBIA.

THE KOOTENAI DISTRICT.

From Mr. G. M. Dawson's account we take the following: This district is rugged and mountainous, comprising the south portion of the Selkirk Range and the

Columbia or Gold Range. Between these ranges is a string of lakes. The ranges are not very continuous, and the average height is 8,000 to 9,000 feet above sea level. The country is densely wooded. Two long and deep valleys traverse the district north and south, one occupied by the Columbia River and Arrow Lake, the other by the Kootenai Lakes. The valleys are connected by a transverse valley, containing the west arm of the Kootenai Lake and part of the Kootenai River, by which the lake discharges into the Columbia River.

The rocks are mainly massive granite, overlaid in places by stratified rocks. The oldest stratified rocks are mica-schists and gneisses, also some coarsely crystalline marbles. The gneisses, especially near the marbles, sometimes pass into quartzites. Overlying these at Hot Springs are gray and green schists, the latter a diabase schist. This series may be unconformable and newer than the Archæan. Over these are massive gray limestones, sometimes changed into marble; below this is a conglomerate. The green schists are composed of volcanic material made schistose by pressure. The thickness of the whole series is 32,000 feet.

Most of West Kootenai consists of massive granite or granitic rock, with numerous dikes. Some of the granites are hornblendic and porphyritic. They are of intrusive origin and of later date than the stratified beds. They are intimately connected with metalliferous veins in the stratified rocks. Granites of the recent class of a pinkish color occur as dikes cutting through the gray granites.

With the exception of the Poorman mine and one or two others, the mines are in the stratified rocks. Exceptional veins traverse a hard, dark gray mica syenite, and are gold bearing, associated with iron pyrites in quartz. Those in stratified rocks carry galena, blende, pyrite and silver. On Toad Mountain the ore deposits are confined to isolated areas of bedded rocks, eleven miles by two, surrounded by gray granite. The country rock consists of altered volcanic material of perhaps Paleozoic age, and is derived from a detritus of a diabase porphyrite. A greenish gray rock, with coarse porphyritic crystals of plagioclase and pyroxene, is very characteristic. The occurrence of these ores in green, altered volcanic rocks shows that these rocks may become a metalliferous series when other conditions are favorable. Those conditions may be fissures segregating minerals.

The Spokane mine, near Hot Springs, occurs near a wide belt of quartz and a dike of augite-andesite. In the vicinity of "Number One" mine the rock is limestone; the direction of the veins is north and south, cutting across the stratified rocks. The lowest tier of deposits in the mica schists yields twenty to forty ounces of silver, while further up selected ores give eighty to three hundred ounces to the ton. The richest deposits are in limestones and black argillites. The ore is principally argentiferous galena, decomposed in the limestones to carbonates for some depth; native silver and gray copper also occur. The ore is usually found in irregular pockets and impregnating the limestone, as at Leadville, Colorado. The ore deposits on the Hendrix Peninsula are low grade, but the deposits are numerous and the ore bodies large.

The Rossland District. The following is taken from the account of the "Ore Deposits of Rossland," by E. B. Kirby, E. M.:

This district began active production in 1894. The total yield up to January 1, 1904, was about $26,000,000 gross value, or an average of $16 per ton in gold, silver and copper. The principal mines are the Le Roi, War Eagle, Center Star and Le Roi No. 2. The ore is carried by rail to the Columbia River, and supplies extensive smelting works at Trail and Northport.

The ore deposits are adjacent to an elongated oval area of gabbro, surrounded by a border of varying width of augite and uralite porphyrites and fine-grained green diabases. The transition from the gabbro to the porphyrites is not well defined, and they are both from the same magma. Beyond the above border comes alternating series of porphyrites, tuffs and slates, and beyond these are agglomerates. All the indications are of an ancient volcanic center. The gabbro area is the main neck of lava, crystallized at great depth and exposed by deep erosion. The active mining has been carried on, not within the gabbro area, but outside of it, and in the porphyrites surrounding its western end. The principal mines are all included in the small group of claims near the edge of the gabbro and located on the flank of Red Mountain, above the town of Rossland. On the west of these claims is a belt of fine-grained eruptives, probably porphyrites, which are in a schistose condition, frequently resembling slate.

The country rock of the mines is evidently all from the same magma, but shows innumerable variations in rate of cooling and degree of metamorphism. It is mainly plagioclase feldspars and pyroxene, generally in about equal proportions, with occasional bodies of pure pyroxenite towards the gabbro area. There is usually a small proportion of orthoclase and sometimes hornblende. The rock appears to be holocrystalline and more or less porphyritic. The feldspars are more or less altered to a turbid or porcelain-like appearance, while the pyroxenes are partially transformed to fibrous minerals of the uralite group. Within the veins the rock is frequently colored brown from microscopic crystals of secondary biotite.

This country rock is cut by numerous dikes, which appear to be either mica traps, or altered and often greatly decomposed basalts. Occasional belts of special crystallization in the country rock indicate dikes of an earlier date, which have since become cemented with the country rock and jointed to correspond with it.

The veins are shear zone fissures, consisting of a series of parallel platings of the rock, produced by shearing under high compression. In the Center Star, Le Roi vein, in which the shear zone is most typically developed, this series of platings is twenty to forty feet wide, and dips about 70° to the northwest.

The ore consists of country rock, more or less replaced or impregnated by pyrrhotite, accompanied in places by small proportions of chalcopyrite, pyrite, arsenopyrite and quartz. The pyrrhotite alone, even in solid masses, carries little gold. The chalcopyrite is the principal carrier of gold, and ore of commercial value occurs only in those localities where chalcopyrite, pyrite and arsenopyrite have been deposited with the pyrrhotite. The manner in which these minerals occur within the interstices of the pyrrhotite, and the fact that continuous masses of pyrrhotite ore are impregnated in some places and barren in others, proves the later deposition of these valuable minerals. A small proportion of the gold in the ore is native in the form of small grains and scales.

The faults have an average direction which corresponds to the dike system, with dips ranging from vertical to 50° easterly. The faults are frequently not plainly marked, having no clay filling, and at most only a small thickness of comminuted material. They frequently consist of a zone or series of close fractures, and these fracture planes often interweave in such a manner that local measurements of their strike and dip are deceptive. As a general rule the faults appear to have been too tightly compressed to give access to mineral solutions, and those existing during the deposition period have therefore tended to act as barriers to the flow of these solutions. Individual faults often cross dikes at sharp angles in strike and in dip. A fault frequently breaks along a dike for considerable distances. Hence, in many cases of vein displacement it is impossible to say how much of the total amount has been due to the dike fracture and how much to the subsequent fault fractures accompanying it. In most cases where dikes are not accompanied by plainly marked fracture planes the displacement is so small as to indicate that the fault system, and not the dike, has been responsible for most of the shifting. In the Center Star the principal channel of solutions has been that portion of the vein between faults. In the lower levels heavy deposition has occurred on both sides of a fault, while on the second level it has been mainly on the east side, and at the horizon is accompanied by a deposition of ore along the plane of the fault. This is exceptional, and is the most clearly marked case of deposition within fault planes. As a rule, the faults do not appear to have been accessible to the solutions.

The shear zone fissures, more or less shattered by repeated movements, have afforded permeable channels for the ascending mineral solutions, which have penetrated and decomposed the country rock. In places the entire width of the shear zone has been transformed into ore. The solutions have frequently jumped across from one set of plating fissures to another, shifting the pay streak from the hanging to the foot side, or to intermediate positions. In the Center Star—Le Roi vein—the foot wall fissure is the one which is the most regular and distinct, and is marked by a vein of small interlacing calcite seams, which have been found a very reliable indicator of the position of the vein. In the War Eagle vein the hanging wall is generally the most distinct and best mineralized, with irregular extension into the foot wall side.

There are peculiar difficulties presented to exploration work within an ancient volcano. Every dike and every zone of fissures constituting a fault creates a gap or blank in the formation, and to these are added the gaps due to vein displacement. Systematic cross-cutting, aided by diamond drilling, is necessary. If carelessly placed, a cross-cut or drill hole encounters so many blanks as to afford no information, or, what is worse, indecisive results. It is very difficult to make such work efficient, and it calls for every resource of care and skill.

ALASKA.

From J. H. Curle's "Gold Mines of the World," the following is taken: Southeastern Alaska, with its inland seas and thousands of islands, is not only one of the grandest bits of scenery in the world, but is also full of mineral, and with quite unequaled facilities for cheap mining, with water power, wood and fuel, and water transit for the high grade coal of Vancouver Island, natural grade for moving the ore from the mines to the mill and for getting rid of tailings, and with bodies of ore that are usually above the normal in size. The ores are of gold, silver and copper. The small mining centers from south to north are Ketchikan, Prince of Wales Island, Sumdum, Douglas Island, Juneau and Berner's Bay. Most of the

FIG. 207.—OPEN CUT OF TREADWELL MINE, ALASKA.

mines are on one or other of the numerous islands, as the mainland, owing to the density of the forests and the presence of the large areas of glacier on the mountains, has not yet really been prospected.

Juneau and Douglas Island are the largest quartz mining districts in Alaska. On the other side of Gustineau Channel is Douglas City and the Alaska Treadwell group of mines. The placer workings, started in 1881, on the beach of Douglas, led up almost at once to a wide gold-bearing formation outcropping on the slope of the mountain only a few hundred feet from the seashore. On this lode the Alaska Treadwell, the Alaska Mexican and

FIG. 208.—A TYPICAL PROSPECT IN NORTHWEST ALASKA.

the Alaska United are now running 880 stamps and their open quarries extend along it for more than a mile.

This immense lode, said to be a true fissure, was, in one place at the outcrop, over 400 feet wide. It is in many other places along the surface 100 feet wide, and

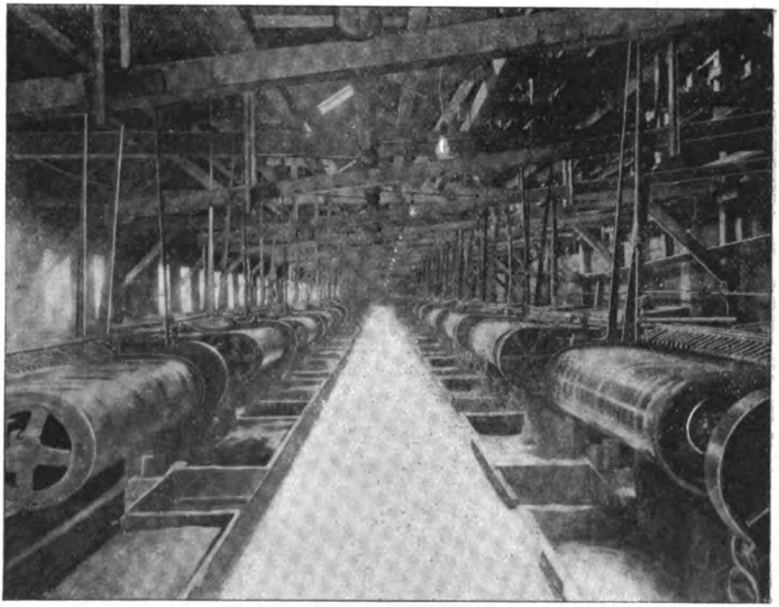


FIG. 209.—CONCENTRATING TABLES, TREADWELL, ALASKA.

even at a considerable depth is found to be 80 to 100, or even as much as 150 feet wide. Here and there, where the slate walls press in, it narrows to a mere stringer and loses much of its' area by the intrusion of bodies of diorite and slate. Its bulk is truly colossal and its continuance in depth seems assured. The lode is a dike of eruptive rock, altered to, or highly impregnated with quartz carrying pyrite. It is free-milling as to about [illegible] of its gold, and as the pyrites concentrate perfectly, it may be called an ideal ore to treat. The length of the lode is not yet defined. It runs parallel with the beach and dips under the sea at an angle of [illegible] degrees. This lode is good for nearly two miles in length, but at each

[illegible]

[illegible]
[illegible]

[illegible]
[illegible]
[illegible]

There is a good body of ore, which means cheap mining. The ore is easy to blast down to crush in a mill, and is most easily treated. Something like 60% is saved in the mill as free gold, and after the tailings have passed over Frue Vanners, on which the pyrites are concentrated, hardly any gold is left in them. The tailings are run direct into the sea and are swept away by the tide, thus disposing of what is often an awkward problem. The fall between the mine and the mill saves labor in handling the ore. There is water power to run most of the machinery for all the year. Elsewhere in Alaska the water usually freezes in the winter. Water power produces electric lights for the mines above and below ground and compresses the air to drive an aggregate of 60 rock drills. There is water transit to the mines and a deep water wharf within a few hundred yards of the shafts, insuring cheap carriage of supplies and fine coal from the south, and the dispatch of concentrates to the smelter at Tacoma in the empty coal steamers. To all this may be added the best American work in mining and labor-saving.

The Treadwell portion of the lode is worked extensively as an open quarry. Below the open workings are three levels, the lowest at 440 feet. Above this level it was estimated that over 4,000,000 tons of ore were in sight. The mine crushes over 500,000 tons of ore of very low grade every year. There are 540 stamps in mills of 240 and 300 stamps each. The 300 stamp mill is considered the finest in the world, for each stamp can crush four and a half tons per day at a cost of about 6d. per ton.

CHAPTER XXIV.

TIN IN ALASKA.

We have at last, it appears, found some fairly promising tin deposits in North America, judging from the description given by Arthur J. Collier, of the United States Geological Survey, of those of the York region of Alaska. It has long been the expectation of mining geologists that tin would be found some day in good commercial quantities in America, and considering the geological conditions of this favored land, it has only been a wonder that it has not been found in abundance long ago.

Tin has been found and known to exist here and there in various parts of North America, e. g., in the Black Hills of Dakota, the Temescal region of California, and in various places in Texas and at Durango, Mexico, but nowhere so far has it apparently been in sufficient quantities as to warrant a large industry like those of Cornwall, England, or of some of the islands of the South Seas.

As is usual with many rare minerals, such as gold. platinum, etc., the discovery of the ore was first in working placer deposits, where it occurred in the form of so-called "stream tin," then these were traced up to the parent rock, where ore was in place.

In 1900 Mr. Alfred H. Brooks, of the United States Geological Survey, visited the York region and found tin in the placers of Anikovik River and Buhner Creek. Since that time tin ore has been found both in lodes and in alluvial deposits at a number of widely separated localities. In the geology of the York region, four distinct rock types have been recognized, including slates, limestones (probably of Paleozoic age), and some granular acid intrusive rocks. It is in these latter that the tin deposits occur. The rock is a white, coarsely crystalline, somewhat porphyritic granite, made up of quartz, microcline and biotite mica, containing, as accessory minerals, albite, muscovite, zircon, apatite, tourmaline, pyrite and fluorite. These granites have been considerably affected by processes which have produced various forms of granite called "Greisen" by the German geologists. The distribution of the granite is of the greatest economic importance, since it is in granite dikes and near their contacts that the lode-tin deposits have most frequently been found. Unconsolidated gravels and silts cover the broad coastal plain along the Arctic coast and in the creek beds. In them is found the stream tin.

Tin ore has also been reported from a great many other localities, which have not been thoroughly examined by geologists. The tin deposits do not follow any definite system and are confined to no particular belt or zone. The principal known occurrences of tin ore are at Lost River, Cape Mountain, Buck Creek, Buhner Creek and Anikovik River. On Tin Creek, in the Lost River district, dikes of igneous rock cut the limestone and at the contact such metamorphic minerals as tourmaline, garnet, epidote and fluorite are developed. A white porphyritic dike cutting the limestone four or five miles from the coast, forms the present point of interest to the tin miner. This dike is 100 feet wide, and is traceable a mile. Tin ore has been found in the croppings of this dike, and strewn over the surface along its course, but varies in general appearance and character. Some of the weathered ore from the croppings is highly siliceous and has the appearance of weathered iron-stained vein quartz with small crystals of black cassiterite distributed through it, while other specimens show clearly their granite origin, but contain little quartz. The ore occurs as crystals from the size of a pin-head to a walnut, and as veinlets and irregular masses. Some of this granitic ore is found under the microscope to be much altered from its original character, now consisting of calcite, fluorite, quartz and large crystals of lithia mica. In addition to the cassiterite, tourmaline, pyrite, galena and garnet occur as accessory minerals; also a little free gold; the latter is unusual in tin deposits. Wolframite and garnet are also at times associated with the tin. The tin ore is, in part at least, essentially an altered granite, porphyry or "greisen," having crystals of cassiterite disseminated through it.

The Cape Mountain tin deposits occur in a high peak, which marks the most western point of America. A settlement, called Tin City, has been established, and from the top of the mountain the Siberian coast, only sixty miles distant, is visible. Cape Mountain is composed of granite introduced in limestone, and in this, ore occurs in irregular veins. Large pieces of pure cassiterite, weighing several pounds, have been found on the surface of the mountain. Some of the cassiterite crystals are colorless and transparent. Prospect tunnels have been driven into the mountain, but so far without satisfactory results.

Buck Creek is the scene of the first attempt at tin mining on a practical scale in Alaska, and is the present center of tin mining activities. It is on the Arctic slope of Seward Peninsula, twenty miles northeast of York. Tin ore has been found in the gravels of Buck Creek from its mouth to within a mile of its head. The pay-streak is confined to the present stream bed and flood plain deposits and varies from 10 to 12 feet to 150 feet in width. In the creek bed the ore is found from the surface down. The thickness of tin-bearing gravels varies from a few inches to four or five feet. Estimates of the amount of tin ore in the gravels vary from 8 to 27 pounds per cubic yard. Between 1901 and 1902 several tons of ore were shipped out to the states.

On Anikovik and Buhner Creeks the bedrock is slate, and stream tin is concentrated on bedrock with other heavy minerals; a sample of concentrates from the sluice boxes yielded: cassiterite, magnetite, ilmenite, limonite, pyrite, fluorite, garnet, gold. The percentage of weight was 90% tin stone, 5% magnetite, and other minerals 5%.

There are several reported occurrences of stream tin and of tin in lodes.

The conclusion of Mr. Irving is that cassiterite is rather irregularly distributed through an area of about 450 square miles, embracing the western end of Seward Peninsula.

The tin ore is almost all cassiterite, though a little stannite has been found at one locality. Its original source is in one case in quartz veins cutting metamorphic slates, in the other in more or less altered granitic rocks. This second type of lode gives promise of commercial importance.

In estimating the value of the tin ores it is to be observed that the region is without timber and is accessible by ocean steamers only from June to the end of October. Harbor facilities are poor and wages high, but the construction of railroads is not difficult. All the occurrences are near the sea. Freight rates to Puget Sound should be low, as the large fleet of ocean steamers which run to Nome return empty. Last summer 98,000 tons of freight were brought to Alaska by vessels that called at Nome. It is fair to say that these tin deposits are well worth careful and systematic prospecting.

There is no production of tin within the United States, notwithstanding the large sums of money that have been expended in attempts to mine the ore in California, North Dakota, North Carolina, Virginia, Texas and other places. Should these Alaska fields prove profitable it would be of distinct benefit to the United States.

CHAPTER XXV.

CONCLUDING REMARKS.

Within the past few years our knowledge of mining geology has made rapid strides. Not only has our geological horizon broadened as to the formations and periods, subject to certain physical conditions in which veins may occur; but also our knowledge of the modes of occurrence of the veins themselves has been materially enlarged. Formerly, a so-called *true fissure vein* in granite rocks was supposed to be the one and only type of profitable vein occurrence; now, we have blanket veins, pipe veins, pocket veins, shear-zone veins, impregnated zones, and many other forms of workable ore deposits.

Ores occur in rocks of all the geological periods, and are found in all kinds of rocks. Thus we have ores in volcanic rocks, in granite, gneisses, schists, slates and quartzites, in unaltered limestones and sandstones, in conglomerates, and in placer form in accumulations of unconsolidated clays, gravels and pebbles.

A large addition to our knowledge of the kinds of rocks in which ore deposits may occur was made by the revelations of the Cripple Creek district. Here was a region of untold mineral wealth often passed over by the geologist and the miner, as unpromising, because the volcanic rocks were of an unusual and more recent type than those in which ore deposits had hitherto been commonly found. The older rocks have felt all the throes of the earth from past to present times, and by reason of their subjection to great movement, accompanied by fissuring, and to great metamorphic heat and vast intrusions, have been favorable for vein formations and the deposition of mineral. But it is neither the geological age nor the kind of rock that determines the when and where of ore deposition, but rather dynamic movements, metamorphic agencies and other circumstances. The old andesite volcanic vents, as shown at Cripple Creek and at Rosita, are found to be prolific sources of ore. A new ore-bearing rock, phonolite, was introduced to our notice by the Cripple Creek discovery. It is an eruptive rock, and so far as known is confined, in this country, to the Cripple Creek region and the Black Hills of South Dakota. This rock, which is common enough in Europe, and elsewhere, is not there notable for connection with ore deposits. It is an interesting fact, too, that ordinary basalt of Cretaceous or Tertiary date of eruption which is so abundant both as overflows and dikes, over large areas of Colorado, has not hitherto proven a good ore generating rock; though certain peculiar basalts, known as nepheline basalts, are frequently connected with the ore deposits of Cripple Creek.

A necessary factor for ore deposition in connection with volcanic rocks and eruptions appear to be a great solfataric decomposition of the rocks subsequent to the main eruptions of lava. It is in this solfataric or hot-spring and fumarole period that ore concentration and deposition appear to have taken place. Fresh looking, undecomposed lava regions are not generally favorable to ore deposition, and the throats and flows of modern craters are not noted depositories of the precious ores.

The old prejudice in favor of so-called *true fissure* veins in granitic or crystalline rocks, in contrast to the supposed less to be relied upon and less continuous bodies in blanket veins in sedimentary rocks, such as limestones, has vanished with the experience of twenty years' work on the still persisting blanket veins in the limestones of Leadville; and a similar experience for a shorter time in the limestones of Aspen, Colorado, and in many other parts of the West. With regard to the mode of occurrence in hitherto so-called *blanket veins,* which were supposed to be bedded veins, lying evenly like coal seams between two sedimentary rocks, or at contact of an overlying sheet of porphyry with an underlying sedimentary bed, the ore deposits of Aspen have revealed to us the fact that, in some cases at least, these supposed bedded veins occupy a true fissure or line of dis-cission between one stratum and the other, or on the line and at the crossing of an intersection of various kinds of faults. Again it has been found by development at Leadville that the ore-bearing zone was not confined to one persistent layer along the contact of the porphyry and lime, but that the ore deposits penetrated far downward into the limestone, and, more than this, that the ore horizons occur at different levels all the way down to the granite bedrock.

In regard to the origin of fissure veins the primitive idea of a wide-open crack gradually filled by ore-bearing solutions has given place to that of a zone of rock fissured and fractured and gradually replaced by vein and ore matter by solutions until a wide-appearing vein is the result.

The prevailing association of eruptive igneous rocks with ore deposits is so generallly observed and recognized that it needs little further comment here. It is almost safe to say that, in the West, without igneous rocks in a vicinity no ore deposits of importance are to be expected, and as an almost invariable accompaniment we look for metamorphism and crystallization of rocks.

Apart from the geological conditions and environ ments of veins and ore bodies is the very important consideration as to their continuity and increasing richness with depth. This interests both the operative miner and the prospective investor. In the first edition of this work we combated the once common and even still popular idea with many miners and prospectors of inevitable richness of veins with depth. We pointed out that there was no sufficient basis or scientific reason for such an assumption. We asserted that statistics were balanced as much one way as the other. Observations since then lead us to make still stronger assertions, and to state that experience throughout the world has demonstrated that by far the larger majority of mines and ore deposits do not increase, but decrease in value, if not in size, with great depth. By great depth is meant below 1,000 or 2,000 foot level. The best days of most mines are within the first 1,000 feet, and the exceptions to this rule are far within the minority. The scientific cause for this, if there be one, we do not intend to discuss here, reference has been made to it in the earlier part of the work, but the unques tionable facts remain as stated. This is exemplified not only in Colorado and the West, but over the entire world, as may be seen from a perusal of Mr. J. Curle's book, "Mines of the World," wherein he emphatically says: "The one thing I want to show clearly is that mines do not get richer in depth, but get poorer. A richer patch of ore may be found here and there in the deep workings of a mine; such a phenomenon is an exception to the almost universal rule."

The popular, but untenable, notion of inevitable richness with great depth has come doubtless, in part, from the discovery of lower zones exhibiting the now well-known phenomena of secondary enrichment. While secondary enrichment is an interesting feature of mining geology, and in mines often productive of bonanzas, it in no way sustains the assumption of inevitable richness with great depth, and can not be relied upon to occur generally in mines, but only in those where all the conditions have been favorable for the process.

GLOSSARY

AND EXPLANATION OF SOME SCIENTIFIC AND OTHER TERMS USED IN THE MINING FIELD.

(The descriptions of rocks are mostly from Kemp.)

Acidic, containing more than 65% SiO_2.

Adamantine, of diamond-like luster.

Agglomerate, a special name for volcanic breccias as distinguished from other breccias and from conglomerates.

Alaskite, a silicious granite rock made up essentially of quartz and feldspar. Named by Spurr from Alaska.

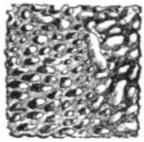
Alluvium, deposit of gravel, sand and mud that usually intervenes in every district between the superficial covering of vegetable mould and the subjacent rock. (Lyell.) Generally used for the earthy deposit made by running streams or lakes, especially in time of floods. (Dana.) From the Latin for inundation.

Amorphous, not crystallized; without any special form.

Amphibole, the generic name for the group of bisilicate minerals whose chief rock-making member is hornblende.

Amphibolite, a metamorphic rock consisting chiefly of hornblende. Usually synonymous with hornblende-schist.

Amygdaloids, cellular lavas with cavities in shape and size resembling an almond. Certain basaltic lava sheets of the Lake Superior region have their amygdules filled with native copper. The name is from the Greek for almond.



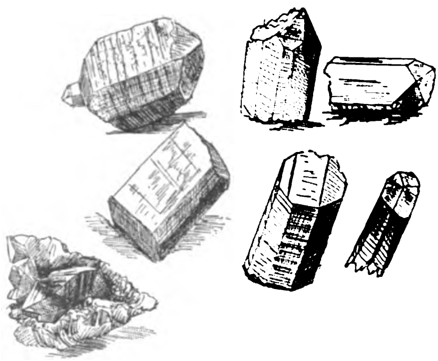
AMYGDALOIDAL SCORIA.

Andesite, volcanic rocks of porphyritic or felsitic texture composed of crystallized plagioclase and either biotite, hornblende or augite. The name was first suggested for certain rocks from the Andes Mountains resembling trachytes.

Aplite, originally applied to granites poor or lacking in mica. Now chiefly applied to muscovite-granite that occurs in dikes. From the Greek for simple.

Arborescent, like the growth of the branches of a tree.

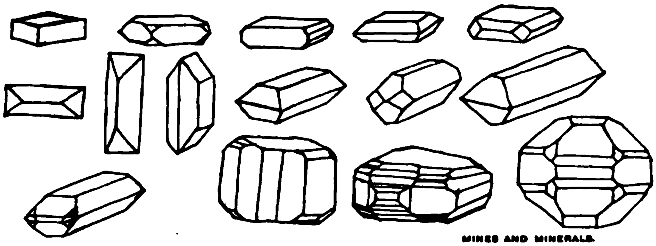
Argillite, a hardened clay.



AUGITE CRYSTALS.

Augite, the commonest rock-making pyroxene. Used as a prefix to the names of many containing the mineral.

Barite, the sulphate of barium. Called also *heavy spar.* Looks like calcspar, but is much heavier and does not effervesce with acids.



BARITE GROUP.

Basalt, in a broad sense, used to include all the dark, basic volcanic rocks, such as the true basalts; the nepheline-leucite, melilite-basalts; the augitites and limburgites; the diabases and melaphyres. In restricted sense is the name for porphyritic and felsitic rocks consisting of augite, olivine and plagioclase with a glassy base which may entirely disappear.

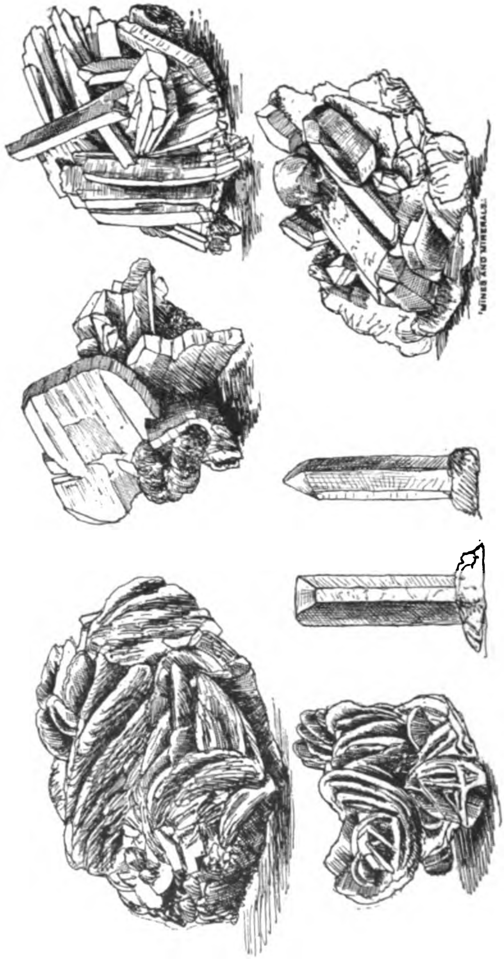
Base or *Basis,* that part of a fused rock magma that in cooling fails to crystallize, but chills as a glass or related amorphous aggregate.

Basic, descriptive of those igneous rocks that are comparatively high in bases.

Bathylite, vast irregular masses of plutonic rocks that have crystallized in depth, and have only been exposed by erosion.

Benches, ledges of all kinds of rock that are shaped like steps or terraces; either developed naturally or by artificial excavation.

Beryl, the silicate of beryllium.



BARITE CRYSTALS.

Biotite, magnesia-iron mica. The name is prefixed to the names of many rocks which contain this kind of mica, i. e., biotite-andesite, biotite-granite, etc.

Botryoidal, presenting the appearance of rounded masses, like grapes.

Breccia, aggregates of angular fragments cemented together into a coherent mass. Breccias often resemble conglomerates, but are easily distinguished, as their components are not water-worn. There are friction or fault-breccias, talus-breccias, and eruptive breccias. The word is of Italian origin.

Calcite, carbonate of lime. Next to quartz, the most common of mineral species. Remarkable for its variety of form both crystallized and uncrystallized; is the same in composition as limestone. Effervesces readily in dilute mineral acids.

Calc-Schist, schistose rocks, rich in calcite or dolomite, and forming transitional rocks between the mica-schists and crystalline limestones.

Calcspar, lime crystals. See calcite.

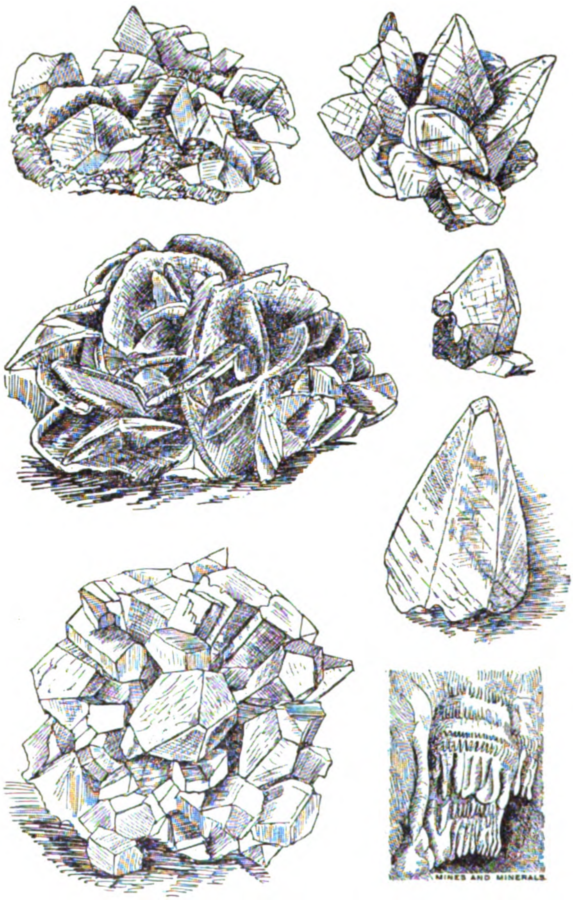
Chert, compact siliceous rock formed of chalcedonic or opaline silica or both, and of organic or precipitated origin. Flint is a variety of chert.

Clastic, descriptive of rocks formed from other rocks; fragmental.

Clay, a general name for the fine, plastic aluminous sediments.

Chlorite, a general name for the green secondary hydrated silicates containing alumina and iron, and derived from augite, hornblende and biotite. The word is from the Greek for green.

Conchoidal, having a shell-like fracture.



CRYSTALLINE FORMS OF CALCSPAR.

Concretions, spheroidal or discoid aggregates formed by the segregation and precipitation of some soluble mineral like quartz or calcite around a nucleus, which is often a fossil.

Conglomerates, rounded, water-worn pebbles or boulders cemented together into coherent rocks. Consolidated gravels.

Contact, the place or surface where two different kinds of rocks come together.

Cross-Bedding, Cross-Stratification, terms descriptive of those minor or subordinate layers in sediments that are limited to single beds, but that are inclined to the general stratification. Especially characteristic of sandstones.

Crypto-Crystalline, formed of crystals of unresolvable fineness, but not glassy.

Dacite, quartz-bearing andesites. Named from the ancient Roman province of Dacia.

Diabase, igneous rocks in sheets or dikes, consisting of plagioclase, augite and magnetite, with or without olivine, and possessing ophitic texture.

Dikes, also spelled dykes, intrusions of igneous rocks. Applied chiefly to vertical or steep intrusions.

Diorite, a granitoid rock, composed of plagioclase and hornblende, with usually more or less biotite. From the Greek to distinguish.

Dolerite, coarsely crystalline basalts. From the Greek for deceptive.

Dolomite, carbonate of calcium and magnesium. Named after Dolomieu, an early French geologist.

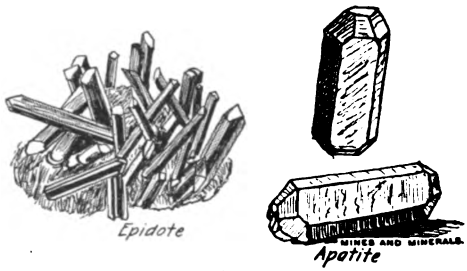
Drift, unsorted deposits of the glacial period.

Ductile, capable of being drawn out into wire or elongated.

Eclogite, a schistose metamorphic rock, consisting of a light-green pyroxene, actinolite and garnet.

Effusive, applied to those volcanic rocks that have poured out in a molten state on the surface and have then crystallized.

Epidiorite, applied to dikes of diabase whose augite is in part altered to green hornblende.



EPIDOTE.

Epidote, a grass-green crystalline mineral. The name is often prefixed to the names of rocks containing it. The presence of epidote indicates the advance of alteration. Composition, a silicate of alumina, lime and iron.

Erosion, the process of the removal of loose material in suspension, in running water, or in wind.

Eruptive, properly applied only to effusive or volcanic rocks, but is often used as a synonym of igneous.

Extrusive, synonym of effusive.

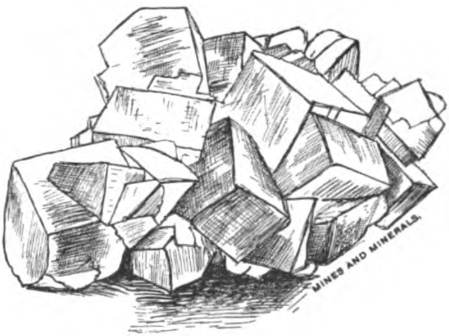
Feldspar. The feldspars and their related minerals are all double silicates of alumina and an alkali or an alkaline earth or both. Grouped, as orthoclase (monoclinic feldspar); plagioclase (triclinic feldspar). Spelled by the English *felspar.* The name is from the German *feldspath,* meaning fieldspar.

Felsite, applied by Gerhard in 1814 to the fine groundmasses of porphyries. Now especially used for those finely crystalline varieties of quartz-porphyries, or porphyrites that have few or no phenocrysts.

Felsitic, having a feldspathic texture characteristic of felsites, i. e., micro-crystalline, but without phenocrysts. Often used to describe the groundmasses of truly porphyritic rocks that are micro-crystalline, but not glassy.

Flint, a compact and crypto-crystalline aggregate of chalcedonic and opaline silica. Chert and hornstone are synonyms.

Float, a miner's term for loose surface ore deposits, which are usually somewhere near their parent ledges.



FLUORSPAR CRYSTALS.

Fluorite, or fluor spar, is calcium fluoride. Occurs in cubic crystals or groups of crystals of a variety of colors, colorless, green, yellow, brown, red and purple.

Foliated, made up of thin leaves.

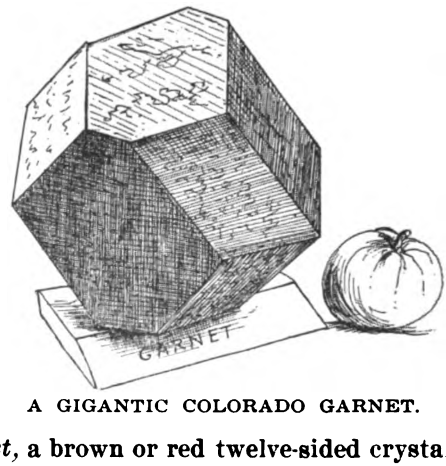
Foliation, the lamination of metamorphic rocks as distinguished from the stratification of sediments.

Formation, a large and persistent stratum of some one kind of rock. Sometimes loosely used for any local and more or less related group of rocks. According to Dana, a group of related strata that were formed in a geological period.

Fragmental, descriptive of rocks formed from fragments of pre-existing rocks, such as sandstones, breccias; clastic.

Gabbro, an Italian word formerly used for a rock composed of serpentine and diallage. Later applied to igneous rocks of granitoid texture consisting of plagioclase and diallage. As the name of a group it includes those rocks with plagioclase and orthorombic pyroxene as well, and even the peridotites may be conveniently embraced.

Gangue, veinstone. Usually the quartz or altered or decomposed country rock which accompanies ores in a vein or bed.



A GIGANTIC COLORADO GARNET.

Garnet, a brown or red twelve-sided crystal occurring in crystalline and metamorphic rocks.

Generations of minerals in an igneous rock refer to the groups of individuals that crystallize out at a definite period and in a more or less definite succession during cooling.

Geodes, hollow, rounded cavities lined with crystals projecting inward from the walls.

Geyserite, silicious deposits from a geyser.

Glass, the amorphous result of the quick chill of a fused lava.

Gneiss, a laminated or foliated granite. The name originated among the Saxon miners.

Gouge, or selvage. Clay lining one or both walls of a vein, between the country rock and the gangue.

Granite, in restricted signification, is an igneous rock, consisting of quartz, orthoclase, more or less oligoclase, biotite and muscovite, but the name is widely used in a more general sense. The first three may also be combined with either of the micas alone, with hornblende or even with augite.

Granite-Porphyry, a quartz-porphyry with a coarsely crystalline groundmass.

Granitite, a special name for biotite-granite; the commonest of the granites.

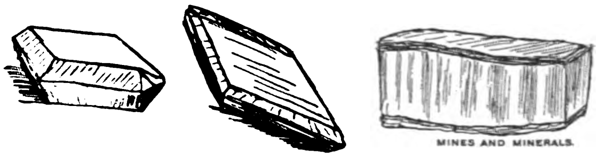
Granitoid, used to describe those igneous rocks which are entirely composed of recognizable minerals of approximately the same size. Suggested by granite, the most familiar of the rocks which show this characteristic.

Granular, made up of distinct grains.

Greenstone, an old field name for those compact igneous rocks that have developed enough chlorite in alteration to give them a green cast. They are mostly diabases and diorites.

Grit, coarse quartzitic sandstone.

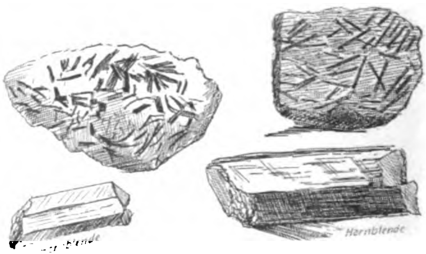
Groundmass, the relatively finely crystalline or glassy portion of a porphyritic rock as contrasted with its phenocrysts.



GYPSUM.

Gypsum, sulphate of lime; occurs in monoclinic crystals, also fibrous, foliated, stellate, and massive as impure earthy gypsum.

Holocrystalline, a textural term applied to rocks that consists entirely of crystallized minerals as distinguished from those with more or less glass.



HORNBLENDE CRYSTALS.

Hornblende, a variety of amphibole which contains alumina; is dark green or brown to black in color. See amphibole.

Hornblendite, a granitoid igneous rock consisting essentially of the mineral hornblende, analogous to pyroxenite.

Hornstone, synonym of flint and chert.

Horses, a miner's term for relatively large fragments of wall rock included in a vein.

Hypersthene, a silicate of magnesia and iron; related to pyroxene in form and composition.

Inclusions, a term applied both to crystals or anhedra of one mineral involved in another, and to fragments of one rock inclosed in another, as when a volcanic flow picks up portions of its conduit.

Intrusive, contrasted term with effusive, and applied to those rocks that have crystallized without reaching the surface. They form dikes, laccolites and bathylites.

Iridescent, having a play of changeable rainbow colors.

Jasper, impure opaque colored quartz.

Kaolin, the hydrated silicate of alumina, that is the base of clays, and that gives them plasticity.

Labradorite, a lime-soda feldspar. The name of the feldspar is prefixed to many rock names. Named from Labrador where remarkably fine specimens were found in 1770.

Laccolite, an intrusion of igneous rock that spreads out laterally between sedimentary beds like a huge lens, and never reaches the surface unless exposed by erosion.

Lamprophyre, a dike rock of porphyritic texture, whose predominant phenocrysts are augite, hornblende or biotite. The word means a shining rock, and was first applied in 1874 to small dikes that were rich in biotite.

Lapilli, volcanic dust and small ejectments, the result of explosive eruptions.

Lava, a general name for the molten outpourings of volcanoes.

Leopardite, a silicious rock, spotted with stains of manganese oxide.

Leucite, a silicate of alumina and potash.

Leucitite, basaltic rocks without olivine in which leucite replaces plagioclase.

Leucite-Basalt, basaltic rocks with olivine in which leucite replaces plagioclase.

Limburgite, dark porphyritic, basaltic rocks, consisting of olivine and augite in a glassy groundmass. They lack feldspars. The name is from Limburg in Baden.

Limestone, the general name for rocks composed essentially of calcium carbonate.

Local Metamorphism, that is contact metamorphism, the series of changes effected by an igneous intrusion. Contrasted with regional metamorphism, which see.

Magma, the molten masses of igneous rock before they have crystallized.

Magnetite, magnetic iron ore. The name of the mineral is prefixed to the names of many rocks in which it is prominent.

Malleable, flattening under the hammer without breaking.

Marble, a metamorphosed and recrystallized limestone. In the trade, applied to any limestone that will take a polish.

Marl, a calcareous clay, or intimate mixture of clay and particles of calcite or dolomite, usually fragments of shells.

Massive, the antithesis of stratified and therefore often used as a synonym of igneous or eruptive rocks as contrasted with sedimentary. As applied to ores it means an uncrystallized compact form.

Megascopic, recognizable by the naked eye. The antithesis of microscopic.

Metamorphism, change of form. The processes by which rocks undergo alteration of all sorts.

Metasomatic, a change of body. The replacement of one or more of the minerals of a rock by others. Especially used in connection with the origin of ore deposits.

Micaceous, made up of thin plates, like flakes of mica.

Mica-Schist, finely laminated metamorphic rocks, consisting of quartz, mica, feldspar and several other minerals.

Micro-Crystalline, granular rocks whose components are recognizable, but so small as to require the microscope for their identification.

Mineralizers, the dissolved vapors in an igneous magma, such as steam, hydrofluoric acid, boracic acid and others that exert a powerful influence in the development of some minerals and textures. Also technically used in some definitions of ores. Thus it is said that an ore is a compound of a metal and a mineralizer, such as copper and sulphur, iron and oxygen, etc.

Minette, a variety of mica-syenite, usually dark and fine-grained, occurring in dikes.

Monzonite, has usually been considered as a variety of augite-syenite. More recently the name has been applied to a transitional and intermediate group of granitoid rocks between the granite-syenite series and the diorites. The monzonites have both orthoclase and plagioclase in approximately equal amounts, or at least both richly.

Muscovite, potash mica.

Necks, lava filled conduits of extinct volcanoes, which have been exposed by erosion.

Nepheline, the same as nephelite, a silicate of alumina, soda and potash.

Nepheline-Basalt, an old general name for basaltic rocks with nepheline, but now restricted to those that practically lack plagioclase, and that have nepheline, augite and olivine.

Nepheline-Syenite, granitoid rocks consisting of orthoclase, nepheline and either hornblende, augite or biotite. The rocks result from magmas especially rich in alkalies, and possess great scientific interest because of richness in rare, associated minerals.

Nevadite, rhyolites that approximate a granitoid texture, i. e., with little groundmass. Named from the state of Nevada by von Richthofen.

Novaculite, excessively fine-grained quartzose rocks supposed to be of sedimentary origin from silicious slimes. They are especially developed in Arkansas, and are much used as whetstones.

Obsidian, volcanic glass.

Olivine, a silicate of magnesia and iron. Its presence marks a basic development. Prefixed to the names of many rocks that contain it.

Oolitic, a textural term for those rocks that consist of small concretions, analogous to the roe of fish. Oolites are calcareous, silicious and ferruginous.

Orthoclase, potash feldspar. From the Greek "orthos," erect, and "klasis," fracture.

Pearlite, a volcanic glass with concentric, shelly texture and usually with a notable percentage of water.

Pegmatite, originally applied to graphic granite, but now used as a general name for very coarse dike or vein granite.

Pele's Hair, a fibrous basaltic glass from Hawaii, named after a local goddess.

Peridotite, granitoid rocks consisting of olivine and pyroxene with no feldspar.

Phenocrysts, porphyritic crystals in rocks, that can be plainly seen.

Phonolite, volcanic rocks, of porphyritic or felsitic texture, consisting of orthoclase, nepheline, pyroxene and more rarely amphibole. Leucite may replace the nepheline yielding leucite-phonolites. The name is Klaproth's rendering into Greek of the old name clinkstone.

Pisolitic, made up of rounded particles like peas.

Pitchstone, a glassy rock, usually corresponding to the rhyolites or trachytes.

Plagioclase. See feldspar.

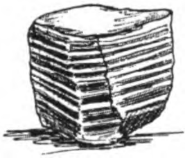
Plutonic, a general name for those rocks that have crystallized in depth, and have therefore as a rule assumed the granitoid texture.

Pneumatolitic, a general name for those minerals which have been produced in connection with igneous rocks through the agency of gases or vapors. The term is much used in the discussion of ore deposits.

Porphyrite, a porphyritic rock, belonging to the plagioclase series and corresponding in mineralogy to the diorites.

Porphyritic, a textural term for those rocks which have large crystals (phenocrysts) set in a finer groundmass which may be crystalline or glassy, or both.

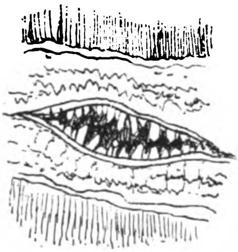
Porphyry, a word derived from the classic name of the shell fish, a species of Murex, that yielded the ancient Tyrian purple. Later applied to the red porphyritic rock of Egypt. In course of time applied to all porphyritic rocks as we now understand the term. In its restricted sense it implies orthoclase-porphyry, the porphyritic rock



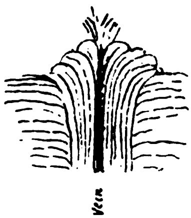
Onyx

Quartz Crystal.

Tourmaline in Quartz.



Quartz geode in a vein.



Banded layer of Quartz.

corresponding to syenite. Porphyry is colloquially used for almost every igneous rock in the West, that occurs in sheets or dikes in connection with ore bodies.

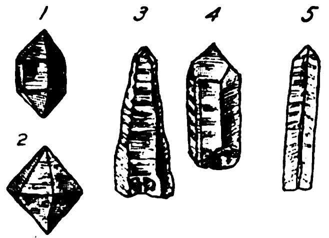
Primary, an old synonym of Archæan. Also used for those rocks which have crystallized directly from fusion or solution, as contrasted with transported or secondary sediments.

Psammite, a general name for sandstones. From the Greek for a grain of sand.

Pseudomorph, the replacement of one mineral by another, such that the form of the first is preserved by the second.

Pumice, excessively cellular, glassy lava, generally of the composition of rhyolite.

Pyroxene, one of the most important of the silicates. The kind called diopside is a silicate of lime and magnesia. Often prefixed to the names of rocks containing it.



Natural forms of Quartz Crystal

Agate geode.

Botryoidal & Stalactitic chalcedony.

MINES AND MINERALS

Quartz, oxide of silicon. The name of the mineral is prefixed to the name of many rocks that contain it, as quartz-porphyry, quartz-trachyte, etc.

Quartzite, metamorphosed sandstone, differing from the latter principally in its greater hardness and fairly pronounced crystalline character.

Regional - Metamorphism, extended metamorphism manifested over large areas, as contrasted with contact effects.

Reniform, kidney shaped.

Rhyolite, volcanic rocks, of porphyritic or felsitic texture, whose phenocrysts are prevailingly orthoclase and quartz, less abundantly biotite, hornblende or pyroxene, and whose groundmass is crystalline, glassy, or both. The name is from the Greek to flow, and refers to the frequent flow structure.

Saccharoidal, a textural term applied to sandstones that resemble the old-fashioned loaves of sugar.

TOPAZ ON SMOKY QUARTZ CRYSTALS.

Sand, fine, incoherent fragments of silica.

Sandstone, consolidated sands.

Sanidine, a glassy kind of orthoclase feldspar found as crystals imbedded in various volcanic rocks.

Schist, thinly laminated metamorphic rocks that split more or less readily along certain approximately parallel planes.

Scoria, coarse, cellular lava, usually of basic varieties.

Secondary, a term used of both rocks and minerals that have been derived from other rocks or minerals, such as sandstone, clay or other sediments; chlorite from augite, etc.

Sectile, can be cut with the knife, as lead.

Sedimentary, rocks whose components have been deposited from suspension in water.

Sericite, aggregates of silvery white shining scales, of mica, composition essentially the same as normal muscovite.

Sericite-Schist, mica-schist whose mica is sericite.

Serpentine, the mineral is a silicate of magnesium.

Serpentine, a metamorphic rock consisting chiefly of the mineral serpentine.

Silicification, the entire or partial replacement of rock and fossils with silica, either as quartz, chalcedony, or opal.

Silt, the muddy deposit of fine sediment in bays, etc.

Slickensides, polished surfaces along faults or fractures produced by the rubbing of the walls upon each other during movement.

Soapstone, metamorphic rocks, consisting chiefly of talc.

Stalactite, depending columnar deposits, generally of calcite, formed on the roof of a cavity by the drip of mineral solutions.

Stalagmite, uprising columnar deposits, generally of calcite, formed on the floor of a cavity by the drip of mineral solutions from the roof.

Structure, used generally for the larger physical features of rocks, as against texture which is applied to the smaller ones. The terms structure and texture are, however, often employed interchangeably.

Syenite, granitoid rocks consisting in typical instances of orthoclase and hornblende without quartz.

Talc, a common mineral often associated with serpentine and chlorite rocks. It is a silicate of magnesium. Is very soft, standing at the beginning of the scale of hardness. It frequently occurs in thin plates or leaves, also massive. Steatite, or soapstone, is a compact variety that shows little if any of the foliated character.

Talc-Schist, schistose rocks consisting chiefly of talc and quartz.

Texture. See structure.

Till, unsorted glacial deposits, consisting of boulders, clay and sand.

Tonalite, a quartz-mica-hornblende diorite.

Touchstone, a black, finely crystalline quartzite, used by old time workers in the precious metals as a touchstone or test-stone to distinguish gold from brass by the streak. Often called Lydian stone or lydite.

Trachyte, volcanic rocks, of porphyritic or felsitic texture, consisting essentially of orthoclase and biotite, or hornblende, or augite, one or more.

Tourmaline, a silicate of alumina, containing iron, magnesia and boron, also, in some varieties, lithia, soda and potash.

Tourmaline in quartz

Tufa, the cellular deposits of mineral springs, usually calcareous or silicious.

Tuff, the finer, fragmental ejectments from the explosive eruptions of volcanoes.

Vitreous, glassy.

Vitro, a prefix meaning glassy, and used before many rock names.

Vugh, a miner's term for any cavity lined with crystals projecting inward from the walls.

Wash, a miner's term for loose surface deposits of sand, gravel, boulders, etc.

Xenomorphic, a textural name for those minerals in an igneous rock whose boundaries are determined by their neighbors.

Zircon, a rather rare mineral. Occurs in various crystalline rocks. It consists of silica and zirconia.

Zircon-Syenite, a name given originally to certain nepheline-syenites rich in zircons. Later used as a synonym for nepheline syenite, but now practically obsolete.

APPENDIX

REPRESENTATIVE FOSSILS OF THE DIFFERENT GEOLOGICAL PERIODS.

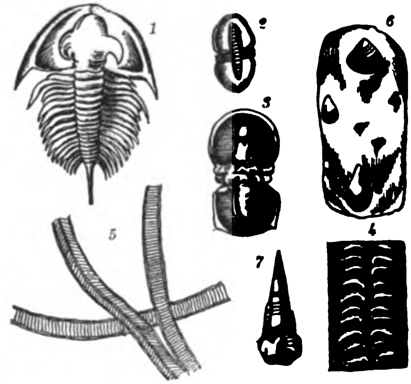


PLATE 21—PALEOZOIC CAMBRIAN FOSSILS.

1, 2, 3—Trilobites. 4—Track of Crustacea. 5—Worm Tracks. 6, 7—Sea Shells. (6 Lingula).

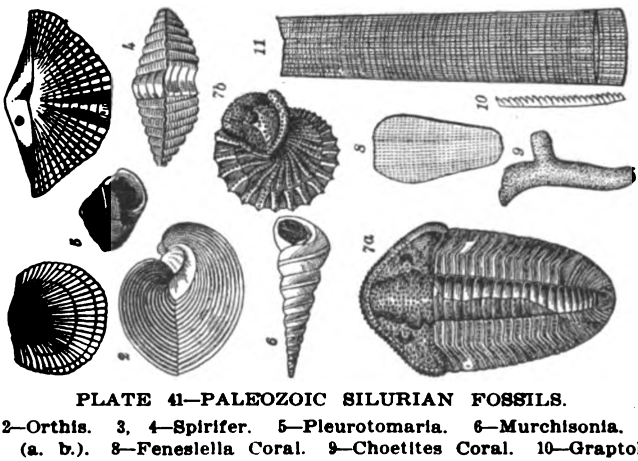


PLATE 41—PALEOZOIC SILURIAN FOSSILS.

1, 2—Orthis. 3, 4—Spirifer. 5—Pleurotomaria. 6—Murchisonia. 7—(a. b.). 8—Feneslella Coral. 9—Choetites Coral. 10—Graptolite. 11—Orthoceratite.

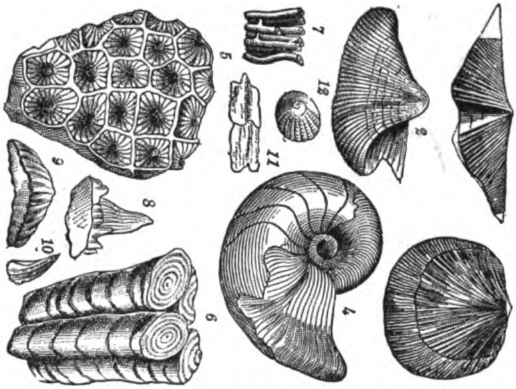


PLATE 62—PALEOZOIC DEVONIAN FOSSILS.

1—Spirifer. 2—Conocardium. 3—Orthis. 4—Goniatites. 5, 6—Corals. 7-10—Fish Teeth. 11, 12—Fish Scales.

PLATE 19—PALEOZIC, CARBONIFEROUS FOSSILS.

1 a, b, c—Productus. 2, 2—Spirifers. 3—Rhynconella. 4—Euomphalus. 5—Crinoids. 6—Pleurotomaria. 7—Bellerophon. 8—Athyris. 9—Astartella. 10—Goniatites. 11, 12—Corals. 13-16—Reeds and Plants. 17—Echinus Spine.

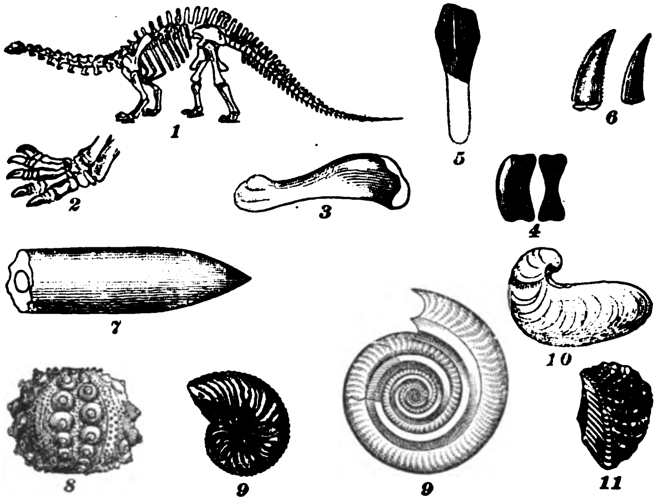


PLATE 17—MESOZOIC FOSSILS OF THE JURASSIC PERIOD.

1—Dinosaur Lizard. 2, 3—Foot and Shoulder Bone. 5, 6—Saurian Teeth. 4, 4—Sea Saurian Vertebræ. 7—Belemnite. 8—Echinus. 9—Ammonites. 10—Exogyra. 11—Trigonia Shell.

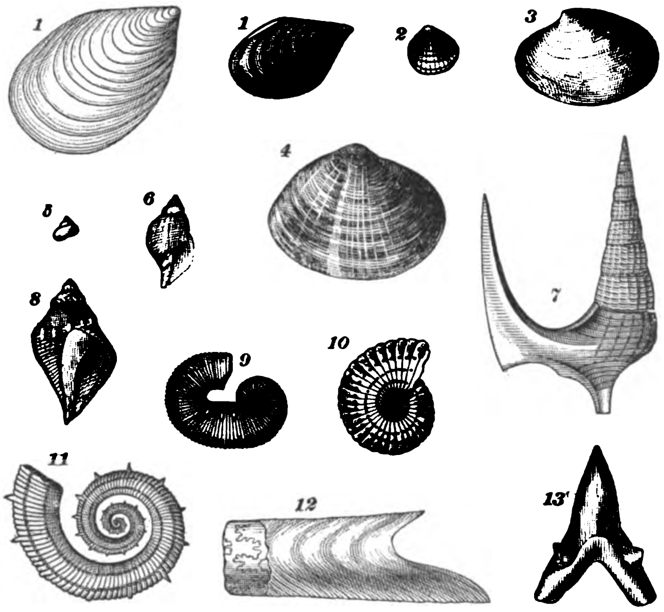


PLATE 38—MESOZOIC FOSSILS OF THE CRETACEOUS PERIOD.

1—Inoceramus. 2—Cardium. 3—Corbula. 4—Mactra. 5—Margarita. 6—Fasciolaria. 7—Anchura. 8—Pyrifusus. 9, 10—Scaphites. 11—Crioceras. 12—Baculites. 13—Shark's Tooth.

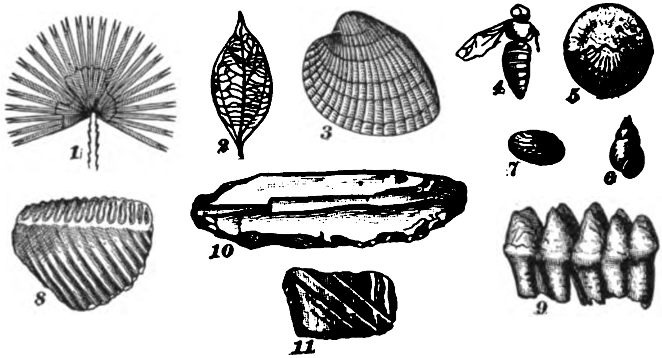
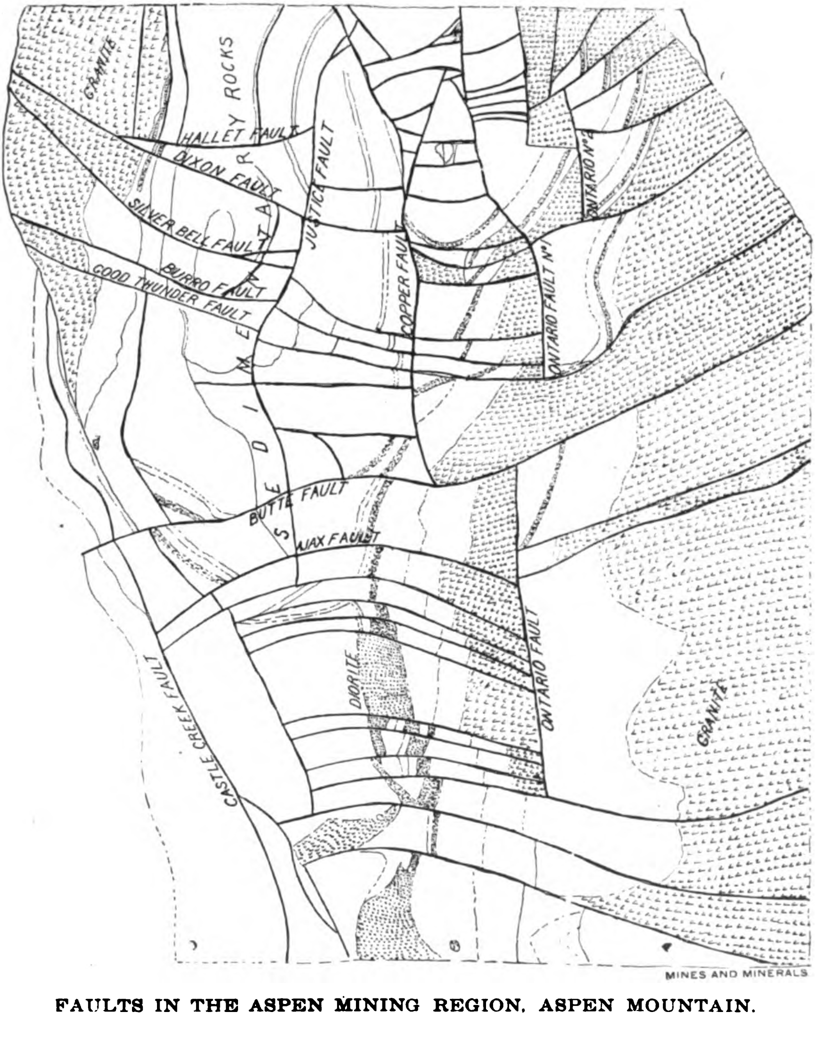


PLATE 35—CENOZOIC TERTIARY AND QUATERNARY FOSSILS.

Tertiary: 1—Palmetto. 2—Cinnamon Leaf. 3—Cardium. 4—Insect. 5—Nummulite Shell. 6, 7—Fresh Water Shells.

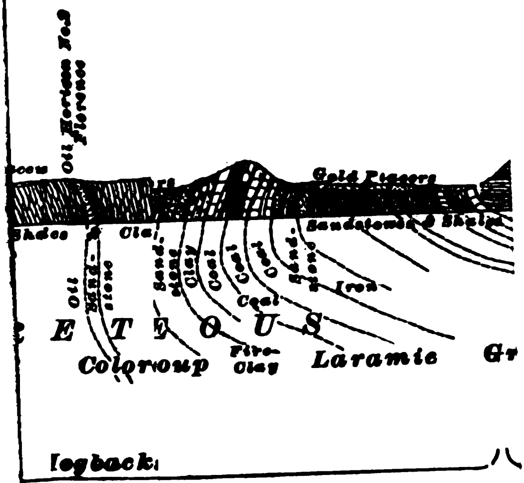
Quaternary: 8—Mammoth Tooth, 9—Mastodon's Tooth. 10—Flint Implement. 11—Rock Grooved by Glacier.



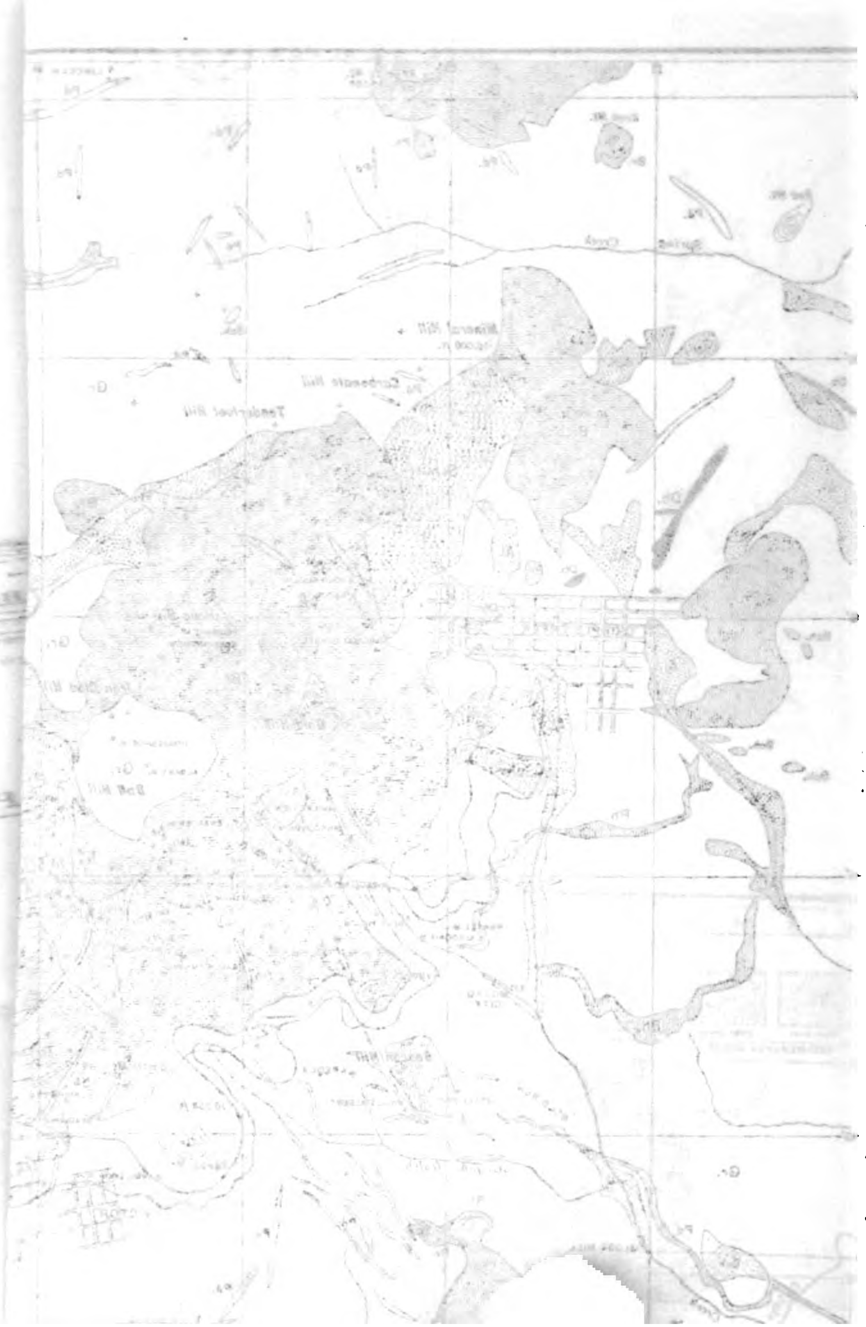
FAULTS IN THE ASPEN MINING REGION, ASPEN MOUNTAIN.

Characteristic		Rocks.	Minerals, Metals &c.	Fossils.
Psychozoic	Recent	Soil, Clay, Pebbles	Some Gold	Man, Buffalo &c.
Cenozoic	Quaternary	Pebbles Sand, Clay	Placer Gold	Elephants teeth, Bones Man Bones, Tools
Cenozoic	Tertiary — Pliocene, Miocene, Eocene	Loosely Stratified Conglomerates, Sands Basalt Andesite Rhyolite Lavas Conglomerates Sandstones Shales & Clays Some of Volcanic detritus, others of Granitic detritus	Old Gold Placers in California Lava-Gold & Silverbearing Thin Lignite Coal Metamorphosed Sandstone Gold bearing in California also Asphalt in Colorado and California	Fossil Leaves Mammals in California Marine Shells
Mesozoic	Laramie	Clay Coal Beds Sandstones	Coal	Leaves, Trees &c. Sea Shells
Mesozoic	Cretaceous — Colo.	Drab Shales Clays Limestone Dark Shales	Canon City Oil Horizon Flux Lime Clay, Iron, stone	Scaphites Baculites Sea Shells Inoceramus Oysters
Mesozoic	Dakota	Conglomerate Sandstone	Fire Clay	Leaves of trees
Mesozoic	Jurassic	Variegated Clays Red marls, Sandstone Lime Stone	Gypsum Oil and Lime & Red Building Stone	Dinosaurs Colo. Sea Shells in Wyoming
Mesozoic	Triassic	Thin Lime stones Thick Red Conglomerate Sandstone	Copper Silica for Glass Silver, Reef Sandstone Some Red Building Stone	Foot prints of Saurians
Paleozoic	Carboniferous	Gypsiferous Shales Reddish Conglomerate Eastern Coal Beds Shales Sandstones Grits & Shales	Eastern Coal of Pennsylvania	Land Plants
Paleozoic	L. Carb	Blue Limestone	Silver, Lead	Corals Sea Shells, Spirifers, etc.
Paleozoic	Devonian	Reddish Sandstone Lime stones	Eureka, Nevada Silver, Lead Deposits	Sea Shells Fish Corals
Paleozoic	Silurian	Drab Pale Limestone Dolomite	Marble Silver, Lead Iron	Sea Shells Crustacea Trilobites Corals
Paleozoic	Cambrian	Slates Quartzites	Gold	Sea Shells
Archæan	Pre Camb.	Quartzites, Conglomeritic Gneiss, Schist Slates, Marble	Gold, Silver Lead, Zinc, Copper &c. Iron	Few Positive Signs of Life
Archæan	Archæan	Granite, Gneiss Schist, Syenite		

PLATE 57—GENERAL GEOLOGICAL TABLE OF THE ROCKY MOUNTAINS FOR MINERS AND PROSPECTORS.



NTINS AND.S OF COLORADO.



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