The Ore Deposits of Goldfield—I

By Augustus Locke*

Goldfield developed as a boom camp where promoters, speculators and lessees delimited the ore-bearing ground and then gave way to the consolidations which followed. Ore never occurs in unaltered rock but usually in rock which is well silicified. The productive area may be considered part of an irregular lode, the walls of which are better defined in dacite than in latite.

The Goldfield discoveries were antedated several years by those of the Yukon and the Seward peninsula. Their lateness has caused much wonder; it has seemed to be something of an anomaly that Nevada should hide its wealth longer than Alaska. The conditions which surrounded the Goldfield discoveries, however, rendered them more difficult than the discoveries in any notable North American gold district.

In the first place, the Goldfield district, though not so remote as Nome or the Yukon, was, in reality, further from the beaten trail. The forbidding Nevada desert offered no motive for exploration except that of prospecting. Even now, when the state contains several centers of successful mining enterprise, it possesses interior expanses of which little is known.

Ore Difficult to Recognize

The ore deposits themseves were intrinsically hard to recognize. The region was by no means entirely unknown, from the sixties onward, the excitements at Montezuma, Lida and Silver Peak had brought prospectors to the vicinity, and in 1902, some months before the initial discoveries, a genuine invading horde had come in, applied their energies for a time to prospects near the sites of the present mines, and then gone away. But, in spite of these explorations, the existence of the Goldfield ore deposits was still unsuspected. There was nothing to hold the gold-seeker's eye; rusty, siliceous ledges existed in vast quantity, and good ore reached the surface in several places, but the croppings which carried gold were effectively hidden in the multitude of their similar brethren which carried no gold whatever. The country had that "burnt up" aspect which the miner associated with the idea of barrenness. Moreover, the sign of the placer was lacking. In other localities, placers have served as infallible trails, easily recognized and yielding such rich rewards that, once found, they were inevitably and instantly followed. The remarkable fact is, not that the Goldfield deposits were so long undiscovered, but that they were discovered at all.

It was in 1901 that Tonopah became a noteworthy producer. Like California in the fifties and Virginia City in the sixties and seventies, it constituted, during its early days of prosperity, a source of prospecting impulses, and overflowed with men, eager to follow whatever gleams of hope the desert afforded. One such gleam of hope was the discovery, in the latter part of 1902, of float gold on Columbia Mountain, about 30 miles south of Tonopah, and a mile or so north of Goldfield. The resulting stampede, and the quick discouragement and departure of the stampeders have been noted already.

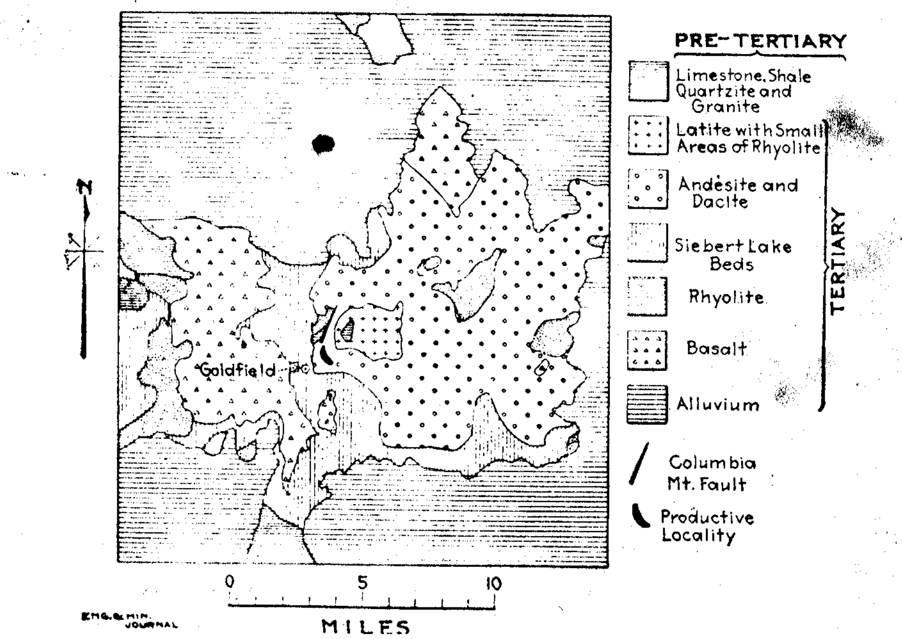
A few prospectors, however, remained, and in the spring of 1903, a location was made on the Combination. Shallow holes revealed ore which was later to be mined in open cuts. Almost from the start, the orebodies developed automatically, paying for their own exploration. The first shipments were made in November. By the end of 1904, the production amounted to half a million; by the end of 1905, it amounted to a million. The Combination had immediately become a great mine.

The discovery of the Combination was quickly followed by the discoveries of most of the other orebodies which apexed at or near the surface. The Jumbo, January and Florence were actively and successfully worked by lessees during 1904 and, during the year, the high-grade portion of the Jumbo and the greater part of the January were worked out. Up to the end of 1904 the total production was as follows: January, $500,000; Jumbo, $1,100,000; Florence, $650,000; Combination, $500,000; total, $2,750,000.

The important discoveries in the Red Top were deferred until the beginning of 1905. The long delay would seem surprising; for in one place ore has since been stoped to the surface. A consideration of the facts affords an explanation; the finds in the Jumbo, Florence, Combination and January were so scattered as to give little suggestion of the trend of the ore, and the relations of the individual ore occurrences to each other were exceedingly puzzling.

At the beginning of 1906, the parts of the district known to be ore bearing are to be regarded as the outliers of the far richer central portion, that of the Mohawk, which was still unrevealed. The Jumbo, the Red Top, the January, and even the Florence and Combination, are according to present indications, shallow mines; they have yielded little below depths of 300 and 400 ft. But the Mohawk (or, rather the Clermont, for the Mohawk in its lower levels goes under that name) has rich ore in considerable quantity down to the depth of 1000 ft., and there is a chance that further development will find deeper ore.

The discovery of the Mohawk was delayed by the barrenness of its croppings. For over two years, while its neighbors



Geological Map of Goldfield and Vicinity
(Adapted from Ball)

Note—The work on which this article is founded was done under the direction of Henry Lloyd Smith, professor of mining and metallurgy, Harvard University, and while Mr. Locke was a holder of a Sheldon fellowship from Harvard University.

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were enjoying the full measure of prosperity, the Mohawk was generally scorned. Not until the mining excitement prompted the sinking of numerous shafts (chiefly by lessees) was its worth learned. One of these shafts, quite by accident it seems, found the Mohawk ore in the spring of 1906, at a depth of 250 ft. The very core of the district was now reached, and in 1906 Goldfield yielded over seven millions.

Goldfield Boom Followed the Mohawk Discoveries

Goldfield was in a state of boom the greater part of the time from the early discoveries until 1908. As early as the beginning of 1905, it had a population of about 8000, a number exceeding the industrial need several times over.

It is not, however, to the conditions of the earlier years that the term, Goldfield boom, is ordinarily referred, but to the period succeeding the Mohawk discoveries. By the end of 1906 Goldfield had developed into a speculative bedlam with a population of at least 15,000.

Of themselves, the discoveries had those sensational qualities which create excitement, but it was to certain accompanying conditions that the full flow of this excitement was due. The first and most important of these conditions was the coincidence of a nation-wide industrial optimism. Promoters made clever use of the prevailing speculative tendency. Two hundred shafts were in simultaneous operation and, according to some estimates, the public paid $30,000,000 for shares in Goldfield mining companies. The facts that only a dozen or so shafts are now active, that dividends have been considerably less than $30,000,000, and that the bulk of this amount has been gained by a restricted group of stockholders, show impressively the magnitude of the inflation.

A second important accompanying condition was the prevalence of ore stealing. I like to regard that part of the boom which concerned the inhabitants of Goldfield as a sort of maelstrom, in which money, easy to get and easy to spend, circulated at an enormously rapid rate, giving the illusion of abundance by the frequency of its appearance. Ore stealing added an impulse, indirect but effective, to the maelstrom. The highgrader who got $20 during the day made haste to get rid of it at night. Goldfield was a community containing some thousands of gamblers.

The result of all the conditions together was a mining excitement as intense, though not as prolonged, as that of the Comstock. And it is interesting that the delimitation of the ore-bearing ground was accomplished entirely during the period of the boom, and largely at the expense of speculators. When it had been finished, a few cool-headed organizers stepped in and took possession.

Lessees enjoyed much prosperity in Goldfield between 1903 and 1908. The first important discoveries in all the mines, except the Combination, were made by the lessees. Goldfield had no such inherent characteristics as those of Cripple Creek which made leasing a logical and permanent necessity, it got a hold largely because of the vagueness with which the ore occurrence was at first understood. Its application was an expedient used only during the stage of preliminary development. Once the limits of the ore locality became known, leasing on a large scale ceased.

Curiously enough, leasing and ore stealing coincided closely in duration, and if leasing had not existed, I doubt if ore stealing would have attained its enormous development. It must be understood that the owner of a productive lease was invariably in a hurry; good miners were hard to get, and the lessee who deprived his men of their "right" to steal ore was likely to have no men at all. In short the consenting silence of the lessees made of Goldfield a place in which ore stealing, approved by the bulk of the population, could scarcely be regarded as immoral.

Goldfield Consolidated Mining & Milling Co. Formed

As already suggested, leasing constituted a sort of intermediate stage between the prospector and the large company. Eventually the time came for big-scale operations. Such operations, however, could have been carried on without consolidation; for the unit mines would individually have constituted enterprises of great magnitude. I believe that the scheme of consolidation was first suggested because the Sheets-Ish lease workings in the property of the Combination Mines Co. followed ore from the surface downward into the Mohawk No. 2 claim, threatening the right of the Mohawk company to important orebodies. The possibilities of apex troubles as here suggested were large, and they looked the more ominous because the relations of one orebody to another were regarded as hopelessly complicated. The fear of destructive litigation caused the possible enemies to enter into an alliance which converted them into permanent friends. Just how much trouble was avoided by this alliance is impossible to say, but Goldfield has been conspicuously free from apex litigation.

The motive afforded by the fear of litigation was, of course, only one of several conditions which promoted consolidation. The orebodies were so arranged that they logically constituted a single unit for exploitation. The ore-bearing area was compact and small, and was controlled by a small number of interests. I know of no great gold district where consolidation has been so easy a matter.

Miners Object to Change Houses

For several years after the early discoveries, Goldfield existed in a state of abnormal excitement. Certain conditions which existed during these years, notably ore stealing and high wages, became fixed habits. The breaking of the habits involved serious labor troubles.

The first of these troubles came in 1906. In that year and in 1907 occurred numerous brief strikes, largely inspired by attempts to reduce wages or to introduce change rooms. The miners were in a most sensitive frame of mind, especially those who had been blacklisted in the Cripple Creek labor troubles.

Meanwhile, important changes had taken place in the character of the Goldfield community. The wages of the early days had been rightly high. But now the excitement was over. Railroads communicated with both the north and the south. The population was three or four times larger than the industrial need. The continuance of high wages was an economic anomaly. At the same time, leasing, except in the Florence, had ceased. The large number of small operators in the mines of the Goldfield Consolidated were replaced by a single deliberate management. The odds were turning rapidly against the strikers.

The decisive struggle started in November, 1907. About 2000 men then quit work, their immediate grievance being the desire of the mining companies to make part payment of wages in clearing-house certificates. Any repetition of the Cripple Creek disorders was rendered impossible by the prompt arrival of Federal troops, and under their protection, the mining companies within a short time announced a reduction of wages amounting to something over a dollar per shift. In April, 1908, the miners' union admitted defeat, declaring the strike to be at an end.

The defeat was a complete one. Wages have continued at the figure set during the strike by the mine owners. Ore stealing, through the institution of change rooms, has been mostly done away with. Since 1908, no effective miners' organization has existed in Goldfield.

First Mill Built in 1905

The early production was shipped out of the district in the form of ore. At first, there was a wagon haul of 60 miles. Soon this was shortened to 30, a railroad then reaching Tonopah. In 1905, the railroad reached Goldfield. A 10-stamp cyanide mill was built in 1905 for the Combination mine. Later, its size was doubled. Three custom mills with a total maximum capacity of 70 tons per day, were, according to Ransome[1] running in 1905. The Florence mill was put into operation as a 20-stamp cyanide mill;

[1]U. S. Geological Survey, Professional Paper No. 66, "Geology of Ore Deposits."

this was later enlarged to 40 stamps. Close to the beginning of 1909, the Goldfield Consolidated company put into operation a 100-stamp mill and later in that year, the 20-stamp Combination mill was dismantled.

It was only while leases were in operation, that there was room for custom mills; at present the custom mills are doing little or nothing. Formerly, the Consolidated shipped to smelters the concentrates from its mill and a considerable amount of high-grade ore. In 1911, the shipments of high-grade ore were mostly discontinued and lately a local concentrate treatment plant has been put into operation. The greatest part of the bullion production is now accomplished within the district.

A large part of Goldfield's prosperity is due to the successful application of cyaniding to the treatment of its ores. Goldfield did not have to experiment and wait for the application of this process. Mexican silver deposits, notably those of Pachuca, furnished the motive for the development of the patio process; the quartz veins of California, for the development of stamp milling and amalgamation; the Comstock, for the development of pan-amalgamation; and the Rand, for the development of cyaniding. But when Goldfield got ready, there was a process suitable for the treatment of its ores already in a high state of perfection. No other locality of refractory gold ores was ever discovered under such propitious metallurgical circumstances.

Ore-bearing Area Limited

It is not safe to count on the Goldfield ore area being enlarged. That any important orebodies apexing at the surface remain undiscovered, is entirely unlikely. And as for important orebodies which do not apex at the surface, there is no reasonable warrant for suspecting their existence outside the area which is now productive. A conservative estimate of future production then, must be limited to the locality known to be ore bearing.

The last annual report of the Goldfield Consolidated company states that in the latter part of 1911, its mines had in reserve 600,000 tons of ore, a two years' supply, of a value per ton probably considerably lower than that mined in the past. The Florence mine keeps little ore developed. It is safe to say that in general, above the depth of 300 ft., the ore-bearing quartz bodies have been well prospected, and that the bulk of the ore has been extracted; yet some ore is still being found there. Below 300 ft., ore in important quantities is being mined in the Red Top, Mohawk, and Clermont, and below 400 ft., in the Mohawk and Clermont. On the 1000-ft. level, the Clermont has important orebodies about 400 ft. long. On the bottom level, the 1200, which is the level immediately below the 1000, little prospecting has been done, and the results have so far been negative.

Goldfield has certainly reached, and perhaps passed, the crest of its production. In the last two years, about 20 miles of development work have been accomplished; yet none of the orebodies discovered has a value equal to that of the orebodies of the earlier years. It must, of course, be remembered that the work done on the lower levels is relatively meager in amount. Nevertheless, at present the presumption is that, should the deep ground so far unexplored prove productive, it will be far less productive than the upper levels have been. Even in the last year, the important new discoveries have taken place above the depth of 450 ft. Altogether, the deep exploration strongly indicates that the ore dwindles with depth.

But if it is certain that the life of the district is limited, it is equally certain that it will be much longer than that of the present ore reserves. The deposits so far found have been the more obvious ones. I believe that the discovery of additional orebodies will be gradual and that the great quartz masses will long continue to yield them up. Without any enlargement of the productive area, and without the discovery of important ore below the depth of 1000 ft., Goldfield ought to keep up a production, important though diminishing, for a considerable number of years.

Sketch of Rock Occurrence

The following is from Ransome: "The district is essentially a low, conical uplift of Tertiary lavas and lake sediments, resting upon a foundation of ancient granite and metamorphic rocks."

The Tertiary rocks, as Ransome lists them, are given in the accompanying table, the youngest at the top.

TERTIARY ROCKS OF THE GOLDFIELD DISTRICT—RANSOME

Formation or map name	Petrographic name	Occurrence
Malpais basalt	Dolerite	Flow or flows with a few small intrusions.
Rabbit Spring formation	Breccia, conglomerate and sandstone.	A variable and for the most part thin deposit; probably fluviatile.
Spearhead rhyolite	Rhyolite	Flow or flows.
Poso formation	Conglomerate	Fluviatile deposit. Conformably underlies Spearhead rhyolite and unconformably overlies the Siebert formation.
{ Siebert formation	Conglomerate, sandstone, tuffs and diatomaceous earth.	Lake beds.
{ Mira basalt	Quartz bearing doleritic basalt	Flow intercalated in Siebert formation.
{ Siebert formation	Conglomerate, sandstone, tuffs, etc.	Lake beds.
Espina breccia	Dacitic breccia	Roughly bedded deposit.
Andesite breccia	Andesite breccia	Roughly bedded pyroclastic deposit.
Meda rhyolite	Rhyolite	Flow.
{ Dacite vitrophyre	Dacite vitrophyre	Flow.
{ Chispa andesite	Andesite	One or more flows in dacite vitrophyre.
{ Dacite vitrophyre	Dacite vitrophyre	Flows.
Dacite	Dacite	Sheet-like and irregular intrusive masses passing into flows and breccias east of the area mapped.
Milltown andesite	Andesite	Mainly flows, but some dikes and intrusive masses and with some tuff and breccia. Locally includes some effusive basaltic rocks which are not exposed at the surface.
Morena rhyolite	Rhyolite	Intrusive masses.
Sandstorm rhyolite	Rhyolite	Flows.
Kendall tuff	Rhyolitic and andesitic tuff	Obscurely bedded and in part lenticular deposits closely associated with the sandstorm rhyolite.
Latite	Latite	Flow.
Vindicator rhyolite	Rhyolite	Flow.

The pre-Tertiary rocks are: Alaskite and granite (occurring as large irregular intrusions in shale); shale and quartzite.

All but 2 or 3% of the production has been derived from latite or dacite. The rocks encountered in mining operations are chiefly:

Shale: Thin-bedded, contorted, exceedingly metamorphosed, consisting of fine-grained quartz with pyrite and abundant microscopic black specks, probably carbon.

Alaskite.

Latite: Never fresh. Has marked flow structure. Biotite occasionally fresh. Hornblende never fresh.

Andesite: Distinguished from the latite by absence of flow structure and by frequent freshness of dark phenocrysts.

Dacite: Closely resembles the andesite; distinguished by possession of quartz phenocrysts. The most common rock distinction required in mining is that between dacite and latite: this is often rendered difficult where the rocks are much altered by the presence in latite of blebs of secondary quartz resembling quartz phenocrysts.

Foundation Rocks Pre-Tertiary

The foundation rocks of Goldfield belong to that body of material which constitutes the pre-Tertiary floor over many thousand square miles in this part of North America. Broadly, their age relations to the overlying Tertiary rocks are analogous to those between the "bedrock complex" and the "superjacent series" of the Sierras, and also, I believe, to those between the foot wall and hanging wall of the Comstock.

No fossils have been found in the Goldfield metamorphics; yet fossils of

Cambrian age are known in foundation rocks a few miles distant, and the presumption is that the corresponding rocks of Goldfield are also Cambrian. And because, in California and in some parts of Nevada, the late Jurassic or early Cretaceous time was a period of enormous granitic intrusion, the granitic intrusions of Goldfield are reasonably regarded as belonging to this class.

Concerning the shape of the pre-Tertiary floor, little is known. In Columbia Mountain, which has a relief of 400 ft., and in several places further east, the old rocks emerge as islands. But these are the only islands in an area of some scores of square miles. Immediately south of Columbia Mountain, in the vicinity of the productive mines, the slate and granite are occasionally encountered in the mine workings.

Underground exposures are so fragmentary as to define the floor only imperfectly. Perhaps the old surface is roughened by pre-Tertiary eminences, like Columbia Mountain. Or, it may be smooth on account of pre-Tertiary erosion, or, locally, on account of faulting. About all that we can be sure of concerning the shape and position of the pre-Tertiary floor in the productive locality is this: Its depth below the surface increases directly with the distance southeast from Columbia Mountain. Close to Columbia Mountain it lies at 300 ft. below the surface; one-half mile further southeast, at 1000 ft.; and a little further southeast, in the Clermont, at 1200 feet.

If several layers of rocks, each having a uniform thickness, had been laid down on a floor of basement rocks; and if, subsequently, the basement rocks had been at some point forced upward, so that the surface sloped in all directions away from the top of a dome; then, after sufficient truncation of the dome by erosion, the layered rocks would appear at the surface in rings with a core of older rocks at the center. The Black Hills uplift of South Dakota constitutes an almost ideal example of this condition.

In Goldfield, as Ransome believes, this condition is exemplified, but incompletely. Broadly, if the effects of faulting be taken into account, the grouping of the volcanic rocks is such that the older are nearer to the exposures of slate and granite and the younger are farther from them. Ransome's map shows a roughly circular area of rhyolite and latite, two miles in diameter, containing all of the islands of granite and shale (excepting Columbia Mountain, which owes its position to faulting) and surrounded by dacite and andesite.

Dacite Wholly Extrusive

The matter of the structural relations of dacite and andesite is of little economic importance. Yet it has considerable geological bearing; for the acceptance of Ransome's conclusion that the dacite is partly intrusive and partly extrusive would necessitate the belief that the intrusive phase of the rock passed before our eyes into the extrusive phase, making what would be surely a most interesting situation.

The more important arguments favoring Ransome's conclusions are as follows: (1) There is a steep dacite-andesite contact in the Florence mine. (2) The dacite transgresses the rule of ring distribution. The first of these arguments is weakened by the fact that the contact referred to is so obscured by the extreme alteration of the rock that it seems fully as likely that the contact is one of faulting as that it is one of intrusion.

The second is weakened by the absence of dacite dikes, by the fact that the andesite, as mapped, includes a number of irregularly distributed varieties, and the possibility that the dacite may be merely an additional variety. Indeed, the chief mineralogical difference between the dacite and the andesite is the possession by the dacite of the scattered quartz phenocrysts. Ransome's rock analyses show that the dacite is more acid than the most basic of the andesites and more basic than the most acid of them. Altogether it is noteworthy that the structural relations of the dacite and of the andesite to the other rocks are in the main identical. For example, both rest on latite. And when the two are mapped together as andesite, the andesite ring becomes at once complete. The evidence now available favors the view that the dacite in the vicinity of the mines was wholly extrusive.

Certain hills in the district which are known to have been produced by erosion, possess a relief as great as 500 ft., and this figure may be taken as a minimum for the total erosion.

Post-ore erosion is difficult of determination. There are several conditions which suggest that it was small: (1) The relative youth of the ore; (2) the extreme slowness of present erosion; (3) a marked increase in the complexity of ore and lode from a depth of 600 ft. upward, suggesting an originally shallow deposition; (4) the entire absence of placers.

Siliceous Outcrops Invariable Condition of Ore Occurrence

The Goldfield district is clearly distinguished from the surrounding monotonous expanses by the occurrence within it of siliceous croppings. These lie scattered over an area of several square miles, as Ransome says, they "stud the hills." Not 1% has been proved to cover ore. Yet little ore occurs without them. They, and the buried quartz of which they are the superficial manifestation, are to be regarded as the largest invariable condition of ore occurrence.

The siliceous croppings belong to an area of intense solfataric rock alteration. Within this area, the rock minerals are seldom sufficiently fresh to show good cleavages; the rock itself is either softened, with the production of much kaolin and alunite, or hardened by silicification. A great body of softened rock, it may be said, carries an incomplete siliceous skeleton. The differences in hardness between the softer and harder parts have produced a topography of rough details, but generally subdued elevations, the soft parts being designated by the depressions, and the hard parts by the siliceous croppings.

Surface Indications Misleading

From the time of the first discoveries, the puzzling characteristics of the area of alteration have bewildered the prospector and miner. The distribution of the quartz bodies suggests, not a mineralization which followed dominant fissures, but one which progressed along complex and tortuous channels. How one quartz body is related to another; how silicification is related to softening alteration; and how alteration in general and silicification in particular are related to ore mineralization, are problems of great difficulty. When the fact became known that some of the croppings covered ore, it became at once a question why all or many of them did not do so, and the question has not yet been definitely answered. The surface material is frequently a barren cover which hides ore; one cropping looks as inviting as another. Until the ore-bearing ground had been delimited, the prospector was in a state of frenzied expectancy and indecision, attracted equally by the "surface indications" of some thousands of acres. Moreover, when he made a choice of locality, taking usually a strong outcrop, he often found that his outcrop was a boulder, that his shafts soon passed out of quartz, or that his tunnels even failed to enter quartz. Or, if the outcrop was more than a boulder, he often found that its limits were crooked, he could scarcely call it a vein, for it had no definiteness of trend either on strike or dip.

In reality, the only established rule of association between rock alteration and ore is this: Ore never occurs in unaltered rock, never in rock not to some degree silicified, and usually in rock which is well silicified. The fact that the orebodies lie within the region of general solfatarism establishes a connection, however vaguely it may be understood, between solfatarism and ore deposition. It would seem, at least, that both were results of volcanism. There is no better indication, however, of our ignorance of the fundamental facts of ore genesis, than our failure here to produce useful working theories, and there is no better proof of the present unsuitability of the so called "genetic" classifications to the purposes of the miner.

Ore and Dacite not Coextensive

The map shows the ore area, with the exception of its southern end, to lie wholly within an area of dacite. For a long time, dacite was regarded as the only favorable rock. The statement, "We are in the dacite," was frequently and profitably used by promoters. The situation prompts an inquiry into the causes of the almost exclusive limitation of the ore area to dacite.

In the first place, it is evident that ore and dacite are in no way coextensive. There is no such large coincidence between the ore and the dacite as there is in Tonopah, for example, between the ore and the trachyte, or in Cripple Creek between the ore and the body of volcanic rocks. Large areas of dacite are barren. Even of that particular area which comprehends the ore locality, it is only a limited portion (near the western edge) which is ore bearing. But if ore and dacite are in no sense coextensive, then does the presence of dacite constitute an invariable condition of ore occurrence? Later explorations, and especially those of the last three years, prove conclusively that it does not.

Ore occurs in andesite. As has been already suggested, the ore area runs across the andesite-dacite contact of the Florence mine into andesite, and persists there for several hundred feet. True, the andesite orebodies have been so small as to look insignificant beside those of the Mohawk, but they are sufficient to spoil the rule.

Again, ore occurs in latite. The great orebody of the Clermont 750-ft. level, to which a considerable part of the extraordinary production of the Consolidated during the years 1910 and 1911 was due, lies in latite on the downward prolongation of the ore-bearing quartz of the Mohawk. The ore on the 900- and 1000-ft. levels also lies in latite. The limitation of the chief ore field to the area of dacite, looks, then, far less significant than it did before the mine workings reached below the bottom of the dacite.

Following are five hypotheses concerning the relations of ore and dacite: (1) The source of the ore minerals was the dacite itself, or the magma from which the dacite was derived. For example, the ore may have come from solutions or gases belonging to a period of expiring vulcanism which closely followed the dacite eruption.

(2) Dacite was intrinsically more favorable than other rocks to the circulation of the transporters of gold.

(3) Dacite was more favorable than other rocks to the precipitation of gold.

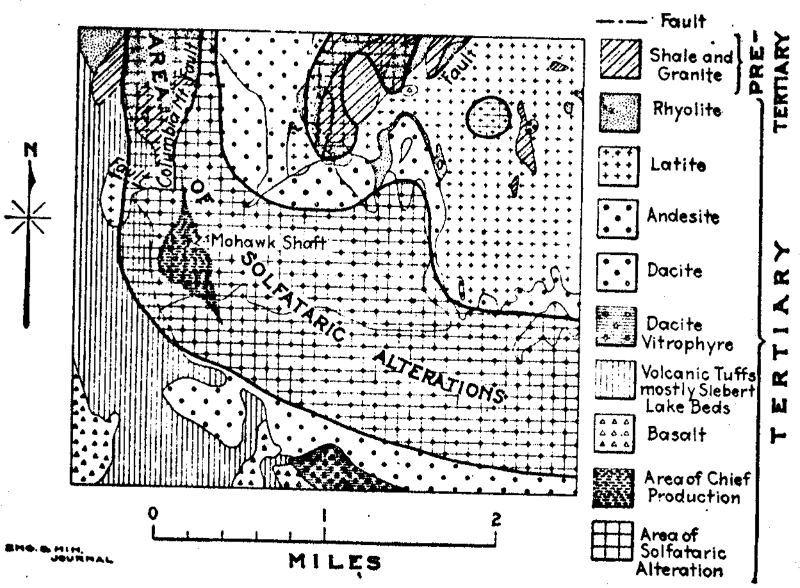
(4) The dacite was localized by faulting. The ore was localized by renewals of this faulting.

(5) The inclusion of the bulk of the productive ground in the area of dacite was accidental.

Concerning the applicability of the first, second, and third of these hypotheses, I have no conclusive evidence. The utter barrenness of large stretches of dacite (the ore belt occupies only one-sixteenth of the dacite area which immediately contains it) creates a strong presumption against them, however.

The fourth hypothesis has plausible arguments in its favor. The ore-mineralizers followed, as seems most likely, fissures belonging to the Columbia Mountain fault movement. Ransome believes the dacite body which contains the ore to have been intrusive and to some extent to have been directed by this same movement. I believe the dacite to have been effusive. But, though effusive, it may possess intrusive roots, similarly directed. Or it may be wholly effusive and occupy a pre-dacite basin whose position was similarly directed. As is stated later, there is no convincing proof that any part of the Columbia Mountain fault movement preceded the solidification of the dacite.

Altogether, the occurrence of ore is a matter of locality rather than of petrography. There is no indication that, had the present dacite area been occupied by andesite, rhyolite, latite, or even shale or alaskite, it would not still have comprehended the ore area.



Geological Map of the Goldfield District
(Compiled from Ransome's maps.)

The Goldfield Lode

The Goldfield ore is chiefly silicified rock-bearing ore minerals; the ore containers are larger masses of silicified rock lacking ore minerals. Ransome believes that the ore containers have not sufficient continuity and definiteness of shape to deserve the term, lode. I have found, however, that they possess greater continuity and definiteness of shape than Ransome's report led me to expect, especially in the levels which have been opened since Ransome's time, those below the 600. Indeed, they are now clearly proved to be parts of a great and complicated lode, having many spurs, curves and interruptions, but showing characteristics which demonstrate its essential unity. It is the presence of this lode which constitutes the second invariable condition of ore occurrence.

The known extent of the lode along the strike is one mile, and along the dip is 2500 ft. These measurements are from the south end of the Florence to the north end of the Red Top, and from the outcrops of the Mohawk to the 1200-ft. level of the Clermont. The siliceous croppings of the lode lie close to the western edge of the area of solfataric alteration, and are weaker than those of many other parts of this area. The sole lode-like suggestion yielded by them comes from the possession of a fairly well marked fracturing striking northerly and dipping easterly, and of a vague north-south orientation.

On the 600-ft. level of the Mohawk, the lode is continuous for a distance of 2000 ft. or more. It has a width, measured at right angles to the walls, of 75 to 100 ft.; it dips 30° easterly.

It is possible to follow this lode upward on its 30° dip and keeping always in quartz, to come out in the Mohawk croppings, or by rising on a steep-dipping, hanging-wall spur, to come to the surface further east. Or it is possible to work northward on the 600-ft. level and, again keeping always in quartz, to come out in the Red Top, or to work southward on the 350-ft. level and come out in the Combination.

The Mohawk, Red Top, and Combination quartz masses, then, have a common root. That the Jumbo and Florence connect with this root has not been proved. The lode crops, as we have seen, near the western edge of the area of solfataric decomposition, and dips under this area. The bulk of the solfatarically altered rock is in its hanging wall, and, in a general way, it constitutes the western and approximate lower limit of such rock. Altogether, there is a strong suggestion that the lode channel was an important route for the travel of the solfataric mineralizers, and that from it they departed upward by devious and manifold paths, into the hanging wall. Following this hypothesis, the barren quartz bodies lying to the east may have somewhat the same structural relation to the lode as the nearer upspringing spurs. The limitation of the productive locality to the foot-wall region of the solfatarically altered rock appears even more strikingly at the Comstock, and is a matter well worth the attention of prospectors.

Lode Better Defined in Dacite Than in Latite

King's famous cross-sections of the Comstock lode, showing a simplification and contraction of the lode from the surface downward, in a large way, represent the conditions as they exist in Goldfield. Not that there is in Goldfield any such well defined foot wall, or that all the superficial quartz masses so definitely connect at depth with a common channel, but that while, in the upper 600 ft., Goldfield has several ore-bearing quartz bodies, in the lower levels; so far as is known, it has but one; and that, again, this one, the persistent quartz body, has an easterly dip on which it extends from the surface to at least the 1200-ft. level, while the other ore-bearing quartz bodies are usually steeper hanging-wall branches.

The most definite lode boundaries exist on the easterly sides of the Combination and of the Jumbo. In these places, the wall is usually marked by a selvage or gouge, and the change from quartz to soft rock is instantaneous. The westerly sides are vaguely bounded. In a direction at right angles to the strike, the silicification diminishes gradually, and there is difficulty in determining where lode material ceases.

Generally speaking, the lode walls are definite when they have gouges and indefinite when they lack gouges. The conclusion is suggested that any sharpness of definition which they may possess is the result of post-lode movement. Ransome expresses his belief in post-lode movement when he states that the gouges have been caused by the squeezing and consequent movement of soft rock around hard kernels (the quartz bodies) which it contains. Altogether, the walls are better defined when the lode is in dacite than when it is in latite, probably because dacite lode material is harder than latite lode material.

Quartz Bodies Weaken with Depth

Ransome's generalization that the quartz bodies weaken with depth survives the developments of later years. The clearest example of such weakening is in the Jumbo. The Jumbo stands vertical or nearly so. At the surface, the quartz is (for Goldfield) excellently defined. At the depth of 300 ft., it is narrower and its outlines are vague. At 600 ft., crosscuts exploring the locality through which its downward continuation ought to pass, have so far intercepted no trace of it. The Jumbo appears to have the non-persistence of a gash vein.

The January acts much as the Jumbo does, a crosscut to it at the depth of 380 ft. reveals only a feeble and barren silicification.

The Combination, apparently, acts somewhat similarly. Since the opening of the lowest, 380 ft., level, questions as to where the lode and where the ore have gone have been asked repeatedly. So far, the most plausible answer is that they quit as they come down to an east-dipping quartz body, and that this quartz body, pitching to the north, forms the connection with the Mohawk.

The Red Top is still strong at the 600-ft. level, some lease workings in a crosscut somewhat over 1000 ft. deep and on the dip of the lode show excellent quartz actually below the porphyries and in the underlying shale.

The Mohawk has great strength on the 600-ft. level. Here it is continuous with the Red Top and the two together are traced for over 2000 ft. On the 750-ft. level, the area explored is smaller, but the lode shows no signs of giving out. On the 900-ft. level, the area explored is still smaller; yet within it, one limit to the well defined portion of the lode has apparently been reached; for to the north the lode merges into a locality of extremely feeble and irregular silicification. It is likely that the quartz comes in strong again further to the north, but at present good quartz is visible for a distance of only 400 ft. along the strike.

On the 1000-ft. level conditions resemble those on the 900. On the 1200, the small amount of exploration work accomplished proves that the quartz is persisting along the dip, but it gives no basis for a generalization as to its persistence along the strike.

Now the three quartz bodies noted as giving out at shallow depths, the Jumbo, the Combination, and the January, are steep or vertical, while the two which have more extensiveness along the dip, possess dips of about 30°. I am unable to avoid the conclusion that steepness of dip is fundamentally connected with persistence in depth.

The Combination quartz weakens when it reaches the dacite-latite contact; the Jumbo and the January quit far above it and the Mohawk and Red Top go down through it. Of what is going to happen when the Mohawk and the Red Top go down into the shale, present developments give us only a hint, that rendered by the single crosscut before referred to, which shows good quartz existing in shale at a point on the downward projection of the Red Top. The 1200-ft. level of the Clermont appears to be immediately above the latite-shale contact.

Three Grades of Quartz

But if the vertical persistence of the lode has no clearly proved general relation to the rock contacts, there is nevertheless a marked connection between them just above the latite-shale contact.

An inspection of Ransome's surface geological maps shows that silicified croppings are abundant in dacite and andesite, but conspicuously scarce in latite. For some reason or other, hard quartz failed to attain any such development in latite as it attained in the other rocks. In my work underground, I gathered much evidence of the general truth of this rule. I found it convenient to distinguish three grades of quartz, the first being flinty, the third soft with much included unsilicified rock, and the second, intermediate. Quartz in dacite, that is, quartz resulting from the alteration of dacite, is chiefly of the first and second grades, while that in latite is chiefly of the third. When the lode passes from one rock to the other, the rule is strikingly exemplified.

For example, the Mohawk comes down to the bottom of the dacite at close to 600 ft. Above 600 ft. there exist huge bodies of hard quartz; below 600 ft. almost the only hard quartz is the ore itself, sometimes 20 ft. wide, and sometimes only half a foot, and the bulk of the lode which attains widths as great as those on the higher levels, is composed of material so soft that the pick in striking it often fails to ring. For the softness of the lode in latite, no satisfactory explanation has been offered.

(To be concluded)

Recovery of Metallic Iridium

Metallic iridium, used for the points of gold pens, is made from the iridium powder left in the wet processes of platinum refining. This powder cannot be smelted alone, says the *Brass World*, Sept. 1912, but is strongly heated in a sand crucible and stick phosphorus added, the mass melting down as iridium phosphide. This is then heated with lime, removing the phosphorus, leaving a brittle white mass of iridium, which cannot be filed or cut, but is broken into the small pieces necessary for pen points, which are ground by carborundum into shape. These pieces of iridium are said to be about the hardness of a ruby.

The Ore Deposits of Goldfield—II

By Augustus Locke *

The lode possesses a number of curious curves in the Goldfield district. Pre-mineral faulting in the plane of the lode is obvious and the ore is localized in fault fractures which constitute mineralizing channels. The relatively small sheet-like orebodies are scattered. The ore is not free milling.

The Mohawk, the Red Top, and the Combination properties, of the Goldfield district, possess along their strikes some remarkable curves. These have strengthened the general suggestion of discontinuity of ore in the quartz; for when the miner, in drifting, has come to such a curve, he has been likely to run on into the soft rock, especially if the boundaries of the quartz are ill-defined, and he has been likely to conclude that he has reached the end of the lode.

The Mohawk Curve

The most important of the curves (most important, because, together with its limbs, it has yielded three-quarters of the output of the district) is that which exists in the Mohawk. The simplest conception of this curve is as a wrinkle or anticline (though it is not properly either) the axis of which pitches 30° or so easterly; the south limb strikes northeast and dips 30°, and the north limb strikes nearly west and stands nearly vertical. The north limb extends for a strike distance of about 250 ft. and then joins a portion of the lode having the normal 30° dip and the same strike as the south limb. The curve is possessed not only by the lode, but by the dacite-latite contact, even in the upper levels where this contact is far in the foot wall.

The curve is plainly visible between the 350- and 750-ft. levels. On the 900-ft. level there are strong traces of it, but because of the meagerness of the exploration, the data are inconclusive, and on the levels below they are even more so. The complication of the lode structure obscures the curve in the upper levels.

The situation, then, is this: On the Mohawk levels, between the depths of 750 and 350 ft., the lode is known to curve sharply around from northeast to northwest, and then, in 200 or 300 ft. to turn back again toward the east. The northeast-striking parts dip flat; the northwest-striking part is steep or vertical. And the dacite-latite contact duplicates the curves of the lode.

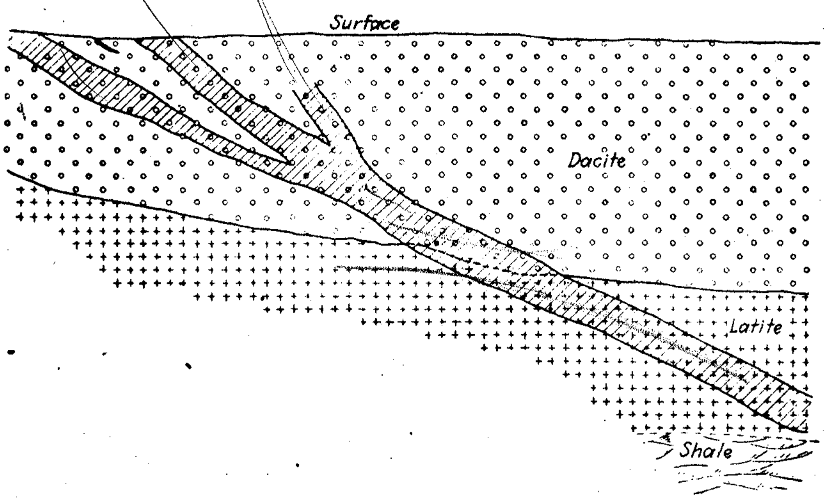


Fig. 1. Diagramatic Vertical Section, Showing Lode on Line of Mohawk, Clermont and Grizzly Bear Shafts

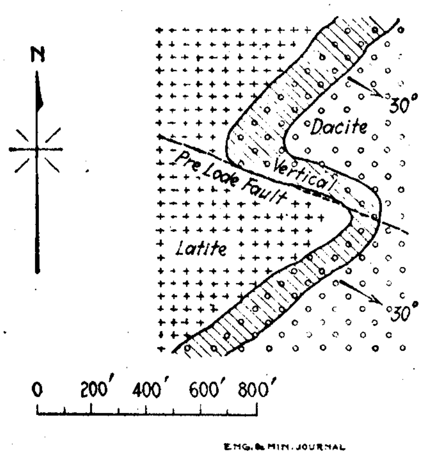


Fig. 2. Diagramatic Plan of Lode Curve on Mohawk 600-ft. Level

No one can study the situation carefully without being puzzled by the Mohawk curve. It is actually difficult at first to realize that the parts of the lode on the opposite sides of the curve are continuous. Exploration, for example, on the 600-ft. level revealed a steep "vein" carrying ore, lying not far north from the flat "vein" and striking at about right angles with it. Orebodies were exploited in both at the same time. Miners looked on the steep "vein" as possibly a spur of the other, but certainly a most inexplicable one.

The steep "vein," it should be said, has a dacite north wall and a latite south wall for a considerable distance below the 600-ft. level, perhaps for as much as 100 ft. The presence of vertical dacite-latite contacts in Goldfield is good evidence of faulting. And surely enough, throughout the whole known extent of the vertical "vein," there exist strong vertical gouges, accompanying and paralleling it; beyond the ends of the "vein," on line with it but out in the country rock, there are additional strong vertical gouges. Altogether, the coincidence of the curve with a fault is sufficiently well established.

Faulting Chiefly Pre-mineral

That the fault preceded silicification and ore mineralization is proved by the fact that ore and quartz occur along it, but the gouges next to the lode sometimes carry rolled pebbles of quartz, and the lode quartz itself is much brecciated. Evidently there was some movement later than the lode mineralization. The amount of this movement, however, was small; for at the junctions of the steep "vein" with the flat "vein," the lode is not noticeably dislocated.

The faulting, then, was chiefly pre-mineral. Evidently, it displaced the channel of mineralization which, as we shall see later, was itself a fault, dipping flatly to the east. The ascending mineralizers came up not only on the original channel, but also on the cross fault which joined its dislocated ends.

The direction and magnitude of the faulting were such that the country to the north of the fault was apparently either depressed a distance of about 150 ft. or moved westward a distance of about 250 ft. The actual direction of movement is not known.

The curve in the Combination is less striking than that in the Mohawk because

Note—The work on which this article is founded was done under the direction of Henry Lloyd Smith, professor of mining and metallurgy, Harvard University, and while Mr. Locke was a holder of a Sheldon fellowship from Harvard University.

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in its vicinity the lode is complex and because the curve therefore is recognizable less in the shape of the lode than in the shape of the dacite-latite contact.

The curve is best seen on the bottom, the 300-ft. level. It is noteworthy that the conditions existing in the Mohawk are here almost duplicated, the main portion of the lode strikes northwest and dips flatly northeast, and the portion of the lode immediately beyond the curve strikes southwest and is vertical.

The vertical dacite-latite contact here again creates a strong presumption that faulting has taken place. And the presumption is supported by stronger auxiliary evidence than is the case in the Mohawk; for the region of the supposed fault shows a zone of exceptionally strong gouges and breccias. On the strike of this zone, there occurs a similar vertical dacite-latite contact in the Clermont shaft, 1600 ft. distant, while the vertical plane connecting the fault in the Combination with the Clermont shaft intersects, in the mine workings, abundant evidences of movement.

The considerations concerning the direction and magnitude of the movement on the Mohawk curve apply here also.

The January Curve

The lode in the January stands steep and, on the whole, is well defined. The curve which it describes for nearly 180° with a radius of not much over 100 ft., is one of the most astonishing details of the Goldfield geology.

The exploration on the dacite-latite contact in this vicinity is meager; no proof has been found of the existence of any faults whose presence would explain the curve. Moreover, it is difficult to see how such a half ring of quartz could be directed by faulting.

Ransome[1] believes that the January follows, not a number of intersecting fissures, but a curved line of continuous fissures, and though it is a fact that fissures tangent to the main curve come in from the walls, Ransome's conclusion is altogether the most satisfactory one. The January is probably localized by curved cracks. What caused them to be curved, and, above all, what caused them to be curved in their extraordinary semicircle, we do not know. They are excellent examples of the eccentricity in detail of the Goldfield lode structure. The Florence probably possesses a curve which is convex eastward.

The quartz, after it comes down to the dacite-latite contact, follows it for considerable distances, both on strike and dip. This fact is best illustrated on the 600-ft. level of the Mohawk, where the hanging wall of the lode is dacite and the foot wall is latite for a strike distance of several hundred feet and for a dip distance of perhaps as much as 200 ft. Not far above the 600-ft. level, both walls are dacite; 50 ft. above the 750-ft. level, both walls are latite. Another, but less perfect illustration is afforded by the lower levels of the Combination.

These conditions suggest that the contact was for a certain distance the localizer of the silicification. But there are some serious difficulties attending the acceptance of this hypothesis. In the first place, if the contact was the localizer of the quartz, then it would seem to be in general a good place to prospect. But prospecting here has been fruitless; the contact is often entirely barren of quartz.

Again, the Mohawk quartz (the east-dipping body, not the spurs which depart upward from it) has a straight dip from the upper levels down to the bottom of the mine, the 1200-ft. level. In its descent, it disregards and is undeflected by the rock contact. On the other hand, the contact looks much as though it were itself deflected by the lode; for both above and below the lode the contact is flatter than it is at the place where it coincides with the lode. On the Combination, the situation is similar.

The hypothesis demanded by these conditions is one of lode-faulting. Now, that there has been post-lode movement in the plane of the lode is obvious. The quartz is filled with fissures, fissures not of entirely irregular tendencies, but having a general parallelism with the lode walls, and constituting so definite a feature that when the boundaries of the quartz are vague, they frequently reveal its real trend. Further evidence of post-lode movements is yielded by breccias almost everywhere characteristic of the lode, and consisting of hard quartz units in a matrix which is chiefly pulverized quartz, alunite, and kaolin.

The evidences of pre-lode movement are harder to see, but no less convincing. The fact that the rock contact follows the lode for a certain distance and steepens when it does so, suggests that the contact was faulted by the lode. And again, the very existence of a lode with a straight dip, traversing at an acute angle and ignoring a contact between successive flows of volcanic rocks, and persisting for a dip distance of at least 2000 ft., is presumptive evidence of previous faulting.

Magnitude of Lode-faulting Uncertain

The only measure which we have of the lode-faulting is its displacement of the dacite-latite contact. In the Combination, this is determined to be about 300 ft., as measured on the dip. (The points at which the contact steepens and flattens are known only approximately.) In the Mohawk, my only positive knowledge concerning the amount of the displacement is that it is between 40 and 200 ft. as measured along the dip.

I have not been able to prove that the vertical or steep quartz bodies follow faults of any considerable magnitude. These bodies, it will be noted, do not pass down through the dacite-latite contact. Until exploration is carried on below them in the contact locality, the question of their throw must remain unanswered.

Ransome maps what he terms the "Columbia Mountain Fault" some distance north of the producing locality but situated on the prolongation of its strike. The fault strikes northerly and dips easterly 20° to 55°. Ransome concludes that its displacement may be as great as 1000 ft.; that the greater part of its movement occurred before the dacite and after the latite had consolidated; that a minor portion of it occurred after the dacite had consolidated, and that this portion was probably the movement which localized the lode quartz.

It is difficult to avoid the conclusion that the lode movements are a southward prolongation of the Columbia Mountain fault movements. But I cannot see any convincing proof that a part of the Columbia Mountain fault movements took place before the consolidation of the dacite. The smallness of the observed displacements in the dacite constitutes no such proof; for it would be expected that in a rock so exceedingly decomposed as the dacite, the movement would be diffused rather than concentrated; that, therefore, no large displacement would be visible in any one place.

The Localization of the Lode Fault

A fault of such flatness and persistence as that which localized the lode in the Mohawk must be regarded as extraordinary. Persistent, flat fissures are known elsewhere, but they either occur in brittle rocks, as at Grass Valley, or they coincide with some structural feature, such as a rock contact. But in Goldfield, the bulk of the rock is soft; the lode ignores the rock contacts, and there is no easily visible structural feature with which it can be connected.

The quartz, as has been before stated, is not "open space" material, but material produced by the alteration of rock. And it possesses peculiarities which denote its lineage; silicified dacite is usually distinguishable from silicified latite. Above the dacite-latite contact, the lode material is universally silicified dacite. Below this contact, the lode, though chiefly silicified latite, has a narrow portion of superior hardness and richness which is not latite.

For some time I was inclined to believe that this portion was a greatly altered dacite dike. It has a width of

[1] U. S. Geological Survey, Professional Paper No. 66. "Geology of Ore Deposits."

one-half to 20 ft.; it has the dark color and flinty character of the typical dacite quartz; occasionally it carries phenocrysts of quartz and always it is easily distinguishable from the softer silicified latite which constitutes its walls.

But although to the unaided eye, it appears to resemble dacite, under the microscope it shows no characteristics which would tend to identify it as such excepting the possession of the quartz phenocrysts. Moreover, it is exceedingly decomposed and silicified, it contains many small fragments of shale and granite, and it frequently has a marked fragmental structure.

There exists, then, in the interior portion of the lode, where the lode lies in latite, a narrow dike-like or vein-like body of quartz, derived by silification from a rock whose characters are observed by alteration, but which looks fragmental. It must be confessed that the evidence contained within this body of quartz is difficult to interpret. But in the latite outside the lode, there are occurrences of similar material whose characteristics are much plainer, and these furnish the key to the riddle.

The material referred to is a breccia which consists of a fragmental rhyolytic matrix carrying numerous inclusions of granite and shale of a maximum diameter of two inches. I found it lying in several tabular bodies not over two feet wide which are apparently limited in extent and detached, yet they usually strike and dip parallel with the lode.

The material is plainly pyroclastic. Being pyroclastic, its existence means that the latite was deposited in successive flows, intercalated with rhyolitic ash. Once it is realized that the latite has a bedding parallel with the lode, it is hard to escape the conclusion that it was this bedding which localized the lode faulting.

The puzzling interior portion of the lode is then a pyroclastic bed. This does not mean that the lode everywhere in latite coincides with a pyroclastic bed; it is known so to coincide only for a distance of about 500 ft. on the dip and of about 500 ft. on the strike. Perhaps, beyond the present exploration, the bed is non-persistent, or perhaps the lode actually leaves it. A not inconceivable situation would be that in which the lode would jump from one bed to its parallel, and not far distant, neighbor.

Upper Portion of Lode Complex

I have sought pyroclastic beds in dacite but have not succeeded in finding them. How then was the lode faulting localized here? I look upon the lode faulting in the dacite as the upward projection of the movement, directed by the latite structure. The lode is more complex in its upper or dacite portion than in its lower or latite portion. It appears that in the latite the fracturing was simple because of the presence of the latite structure, and that in the dacite it was complex because of the absence of any such structure. This does not prevent the acceptance of the hypothesis that the fracturing in dacite owes part of its superior complexity to the superior lightness of the load under which it occurred.

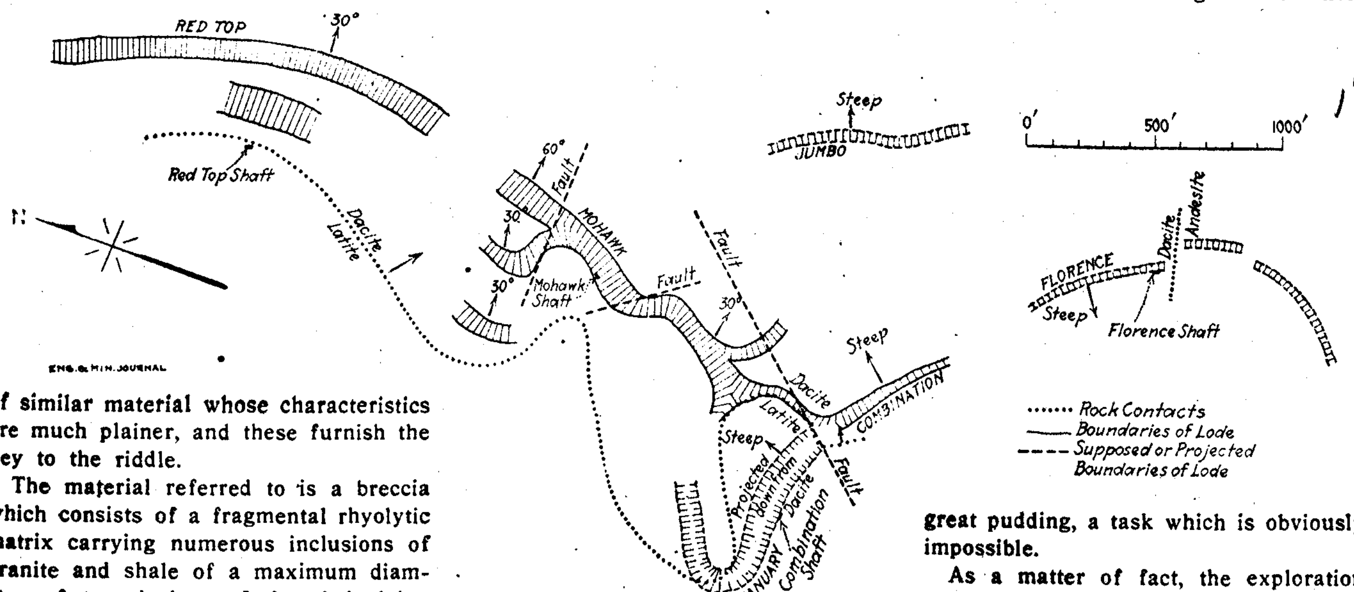


Fig. 3. Plan of Goldfield Lode at Depth of 350 Feet

We have in Goldfield a copy with blurred outlines and on a reduced scale, of the Comstock. In it, the east-dipping lode fault corresponds to the great footwall Comstock fault, and the steep, upspringing branches to the hanging-wall branches of the Comstock. That the Goldfield lode exceeds the Comstock in irregularity of outline is perhaps due to the smallness of the lode-fault movement, to the softness of the rocks in the area of solfataric decomposition, or again, to the absence of "open-space" quartz and to the original absence of well defined and extensive spaces for the circulation of silicifying mineralizers. (These conditions could of course be inter-related.) It will be recollected that the Comstock has brittle rocks, "open-space" quartz in enormous quantity, and a lode-fault displacement of several thousand feet.

Ore Distribution Not Entirely Erratic

The old simile of plums in a pudding illustrates fairly well the distribution of the orebodies within the quartz masses. It applies as accurately to Goldfield as it does, for example, to the Comstock. But we shall widely miss the truth if we conclude that the distribution is entirely erratic, that exploratory work beyond the end of an orebody finds one part of the lode as inviting as another. In the latter part of 1910, the aggregate lode areas revealed in all the levels of the Goldfield Consolidated amounted to about one and one-half million square feet. Of this slightly over 6% was occupied by ore. Now, if the discovery of one orebody gave no clue to the position of its undiscovered neighbor, the task of finding the plums would involve the eating of the whole great pudding, a task which is obviously impossible.

As a matter of fact, the exploration of the quartz masses has in certain cases been almost ideally simple. The exploration of the Jumbo, for instance, was a matter of sinking on ore and drifting on fractures. In certain other cases, a large amount of drifting and crosscutting in barren material has been necessary. Thus, the Mohawk quartz in the upper levels possesses several spurs whose connection with each other is even now not completely traced; the orebodies which inhabit them were at first well hidden.

But even in the Mohawk, the isolation of one orebody from another is more apparent than real. The stopes from which the bulk of the Mohawk and Clermont production has come occur in succession from the 250 to the 1000-ft. level (the distance along the dip of the ore is about 1500 ft.) and are so situated that a straight line can be carried through them. At present, these stopes have the appearance of lying in several discrete orebodies. Had the miner been content to exploit them with less impatience, working gradually from the top downward, he would in all probability have found them continuous.

The haphazard suggestion in the distribution of the orebodies is exaggerated by the frequent fickleness of the gold content. A drift penetrating an orebody may give little indication of the quality of its ore. Important stopes grow from most unpromising indications and, on the other hand, promising indications lead to nothing. Ore cannot be accurately estimated until it has been broken. Because of these conditions considerable time is required to prove the connection between the several parts of a single orebody, and meanwhile the several parts may look like erratically arranged individuals.

Orebodies Relatively Small

The orebodies of Goldfield are smaller than those of the Comstock;

DIMENSIONS OF PRINCIPAL OREBODIES IN GOLDFIELD DISTRICT

Name	Situation	Maximum length on strike. Ft.	Maximum length on dip. Ft.	Thickness Ft.
Hampton	Combination mine N. from shaft...	100	250	10–60
	Combination mine immediately S.E. from shaft......	300	230	5–40
701	Clermont mine 750 foot level.......	150	200	20
	Combination mine N.E. from shaft.	100	180	5–20
	Jumbo............	500	200	1–20

they have no such extent along the strike as is possessed by the orebodies of the Mother Lode in California, or even by some of those in Cripple Creek. The least extensive are excellently described by Ransome as follows: "Small, irregular, isolated bunches of ore, often of high grade, are rather characteristic of the district."

The largest are typified by the orebody on the 750-ft. level of the Clermont which has a strike length of 300 or 400 ft., a dip length of at least 200, and a thickness from wall to wall of 20 ft. The small ore bunches described above have played but a small part in the history of Goldfield. The bulk, even of the richest ore, has come from the larger bodies. A most important peculiarity of Goldfield has been the occurrence of rich ore, $30 to $100 per ton, in bodies of considerable size. This peculiarity has had much to do with the sudden growth and maturity of the Goldfield mining industry; for it has promoted rapid extraction.

Orebodies Possess Sheet-like Tendencies

The following is from Ransome: "In general, the pay shoots are fully as irregular as the ledges with which they are associated. Some of them are roughly equi-dimensional masses, others are lenticular; some are approximately spindle shaped with the large axis nearly vertical, and still others are tabular or plate-like, although such sheets are often curiously twisted or warped. The striking feature of the orebodies as a whole is the absence of, rather than any approximation to, any regularity of form."

I regard the above as a most vivid description of the conditions of irregularity which exist in certain of the orebodies. Yet I am convinced that, in general, it fails to fit the conditions revealed by the more perfect outlining of the orebodies through recent stoping. The larger orebodies are now known to have usually two dimensions, and always one, parallel with the longer dimensions of the quartz bodies in which they lie. In other words, they are extended along the strike and dip of these quartz bodies, and possess sheet-like tendencies.

The first marked sheet-like tendencies are visible in the Jumbo, in the January, in the Red Top, in the portions of the Mohawk which are below the 600-ft. level, and in one or two of the Combination orebodies. The Jumbo stopes look like those of any locality of narrow, well defined veins.

There are a few stopes in Goldfield in which one wall, usually the hanging, is a gouge seam. But visible, well defined walls of this sort, or, indeed of any sort, are rare. The boundaries of the ore are crooked. The miner can seldom count on stopping his work along a given line; bunches of ore protrude out into the wall. Again, the boundaries are not visible. Only diligent sampling can prevent waste from being broken with ore. It is easy to shoot down 10 ft. of $21 material instead of five feet of $40 material.

But that the boundaries are invisible does not mean that they are vague. One of the finest orebodies in the district was barely missed by an exploratory crosscut which passed it at a distance of four feet without detecting the faintest scent of it. The change from high grade to low grade is remarkably sudden; there is no general gradation between ore and waste; and considerable bodies of intermediate tenor ($5 to $10) do not exist.

Feeders Evident within the Lode

Frequently, there occurs within the orebody a seam, one to six inches wide, of high-grade sulphides. The immediately adjacent ore may carry less than an ounce of gold to the ton. Often such a seam occupies the medial portion of the orebody, and parallels it on dip and strike. Sometimes, it hugs one of the walls. Always, it coincides with a fracture or with a group of fractures which have more continuity than the fractures inhabiting the lower-grade material, and on the whole, it is more tabular than this material.

Now the somewhat vaguely tabular orebody with the more perfectly tabular rich seam in its interior is the situation which would result from the original advent of the ore mineralizers through the seam and their permeation of its walls by metasomatism or through restricted openings. In certain cases, there may have been a subsequent enrichment along cracks within orebodies On the whole, however, I am inclined to regard the rich interior seams as ore feeders.

The persistence of the rich portions of the seams is not much greater than that of the orebodies themselves. Yet in quartz outside the orebodies (where the quartz is a derivative of dacite) what appears to be the extension of the feeders is traceable for long distances as barren or low-grade, and usually mineralized, cracks. In the Combination mine, for example, the orebody immediately southeast from the shaft is not known to exist below the depth of 230 ft; but on the 280-ft. level immediately below it, and extending in the direction of its strike, a well defined vertical crack, or sheeted zone of parallel cracks, one to four feet wide, is known for a distance of several hundred feet. The crack or cracks are abundantly mineralized with alunite and pyrite. Often they include breccia whose interstitial spaces are filled with secondary minerals, or they contain bodies of secondary minerals, having diameters as great as a foot. Gold occurs only in spots. On the 380-ft. level the mineralized crack or cracks exist with diminished persistence.

These cracks "feed" up directly into the orebody above. Moreover, they serve to form a direct connection along the strike between the orebody just mentioned and one situated several hundred feet further to the southeast. I do not know that there is any absolute proof in this case that the cracks are older than the orebodies, but their distribution inclines me strongly toward this conclusion.

Feeder Walls Barren

An excellent example of the simple medial feeder is afforded by the Combination orebody which extends from the depth of 230 ft. to the depth of 300 ft. on a dip of 20° to 30°. Here the feeder portion was exceedingly rich, excellently defined, and had a width of several inches; it contained much tough gouge and, though possessing many fragments of quartz, it consisted for the most part of material in a much finer state of division than that of the lower-grade ore. On the 230 and 280-ft. levels the feeder issues from the orebody as a gouge-bearing and pyritiferous seam. To the south, on the lower level, it soon enters latite, and within 100 ft. it is lost. To the north, it joins and is deflected by the strong vertical gouge which constitutes the northeast wall of the main Combination quartz body. As it comes up to the 230-ft. level it steepens until it is approximately vertical, and, as a steep seam, it is traced north for 200 ft. until it mingles with steep cross seams associated with the faulting referred to in the discussion of the Combination curve. South of the orebody it is traced for 400 ft., part of the distance in soft rock.

In its extensions beyond the orebody, the seam carries gold for but short distances, and is distinguishable by a usually well defined gouge. On the 180-ft. and 130-ft. levels it has much the same characteristics as on the 230. The deepest of the ore feeders, and the one which has most certainly been the path of primary ore mineralization, is that on the 1000-ft. level of the Clermont. This is known for a strike distance of about 500 ft. and it has a rich orebody on its southwest end, and a lower grade "base" orebody about 100 ft. from its northeast end.

As has been explained in the description of the lode, the hard quartz of this locality is a silicified pyroclastic bed, lying within a vaguely defined body of rather soft silicified latite. The hard quartz and the feeder coincide. The feeder is excellently shown at the depth of 925 ft. Here its width is one-half to one foot, its dip is 25° easterly, and its black color and flinty hardness distinguish it sharply from the softer and whiter latite-quartz which constitutes its walls. Altogether, it has a strikingly dike-like appearance. But the distinction between feeder and walls in appearance is no more striking than the distinction in value; for while the feeder carries several ounces to the ton, the walls are conspicuously barren.

From the lower levels, the feeder extends upward into the great orebody of the 750-ft. level. I am convinced that from here it rises into the orebodies of the 600-ft. level (though the connection has not been proved) and thence, finally, to the orebodies above.

Feeders Guide Exploration

To trace a feeder requires, as a rule, a great deal of skill. In latite quartz, feeders are usually ill-defined or discontinuous; in dacite quartz, they are often exceedingly complicated, merging with fissures, and weakening or quitting where the quartz softens or where it becomes brecciated. Sometimes to find the feeder is more difficult than to find the orebody. There have been several places, however, where feeders have led the way directly to discoveries, and I believe that with careful study, they could be made to constitute useful guides for exploration.

The richer ore frequently contains pebbles of silicified rock, surrounded by envelopes of ore minerals and quartz. (See Figs. 4 and 5.) The rounded shapes of the ore pebbles have several possibilities of origin: (1) They are waterworn, or (2) they have undergone fault-attrition, or (3) corrosion. The feeder on the 1000-ft. level of the Clermont has excellent pebbles and, as it dips flatly and coincides, as we have seen, with a pyroclastic bed, the sugges-

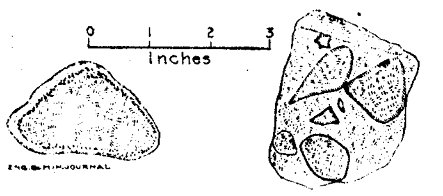


FIG. 4 FIG. 5

Fig. 4. Rich-ore pebble. From interior outwards: (1) Altered latite; (2) crust of sulphides (pyrite, bismithinite, famatinite and pyrite) with visible gold; (3) crust of chalky material (silica and alunite) banded.

Fig. 5. Pebble breccia (low-grade ore), Mohawk 450-ft. level. Pebbles are altered dacite (chiefly quartz with subordinate, alunite and pyrite), each pebble being partly surrounded by an envelope of quartz; immediately inside the quartz is a band resembling rhyolite flow, proving the occurrence of some alteration since time of brecciation. Matrix is fine-grained alunite and quartz with a few sulphides. Dots represent black sulphides.

tion is strong that they may be waterworn. Similar pebbles occur, however, on the upper levels in vertical or steep orebodies, where the chance that they could be waterworn is exceedingly small. For the first possibility, then, there is no convincing argument.

But the feeder of the 1000-ft. level coincides not only with a pyroclastic bed but also with a plane of some movement. The pebbles are conceivably attrition products, and it is entirely certain that the shapes of some of them, such as those shown in Fig. 4 for example, have resulted largely from movement. We may be sure, too, that a certain rounding off or corrosion of corners has taken place since the time of the movement. The low-grade ore (see Fig. 5) shows the beginning of this corrosion. The high-grade ore shows it at its completion. And it is a noteworthy fact that perfect ore pebbles are by far the most common in high-grade ore where mineralization and, therefore, corrosive action was probably most intense.

Post-ore Faults Difficult to Detect

The conditions are such in Goldfield that post-ore displacements are difficult to detect. Where the ore has crooked boundaries, for example, and where the rock outside the quartz is soft and full of curved gouges, there exists no feature by which such displacement can be marked or measured. In those places, however, where a displacement of the ore would be plainly visible, as where there is a well defined feeder or wall, the only considerable known movement is that in the Florence, where Ransome states that the Engineers' orebody is probably displaced from another orebody a distance of 50 ft. The largest post-ore fault which I have seen exists on the 250-ft. level of the Mohawk, and amounts to 10 ft. It is a notable fact that the faults to which the Mohawk and Combination curves are due pass through ore without displacing it and are themselves ore-bearing. Altogether, the evidence favors the conclusion that post-ore movement has been small.

The lease workings of the mines now owned by the Goldfield Consolidated were chiefly within 250 ft. of the surface and their average yield was slightly over $86 per ton. This is no index, however, of the average richness of the ores of the upper 250 ft.; for the leasers left behind much material of lower grade. Up to March 1, 1911, the ore extracted from above the depth of 600 ft. in the properties of the Goldfield Consolidated, both before and after consolidation, constituted four-fifths of the total production, and yielded $44 per ton. That extracted from below the depth of 600 ft. constituted one-fifth of the total production and yielded $80 per ton.

It is of course likely that $80 is a much higher grade than that which these lower levels will produce in the future. But it must be concluded that there is at present no indication of a general lessening of grade with depth.

Ore Not Free Milling

The gold amalgamates poorly and battery-plates are not used in milling. The richer ores contain a small percentage (in certain cases as high as 2%) of tellurium, but while visible gold in these ores is common, visible tellurides are uncommon. Oxidation does not render the gold free milling. The refractoriness of the gold may be due to its extremely fine state of division.

The concentrates of the unoxidized ore are chiefly native gold, pyrite, bismuthinite (Bi_2S_3), and famatinite ($Cu_3[Sb,As]S_4$). There are occasional small bodies of "base" ore, containing several per cent. of copper and zinc. There is no indication of any considerable increase of "baseness" with increase in depth, excepting, of course, that the sulphide ores are more "base" than the oxidized ores. The lower limit of oxidation is at an average distance of 150 ft. below the surface. The silver content is insignificant. The ore, except when exceedingly rich, is not practicably sortable.

The characteristics of the orebodies which have chief importance in the determination of the mining methods are as follows: (1) The hanging wall is heavy. (2) Many of the orebodies have a dip so flat that ore will not run on it. (3) The ore is high grade. (4) The orebodies are moderate in size.

The heaviness of the hanging wall necessitates its support during stoping. The stopes are usually too wide for stulls, and the use of square sets, with subsequent filling, is almost universal. The flatness of many of the orebodies necessitates much shoveling of ore and the frequent use of foot-wall drifts. The richness of the ore necessitates careful and therefore costly, stoping. If the grade were low, the boundaries of the stopes would doubtless be much straighter; for in that case the diligent pursuit of protuberances of ore into the walls would be unprofitable.

The moderate size of the orebodies prevents the use of many labor-saving methods, such as mechanical haulage and the mechanical handling of ore in stopes. It is a suggestive fact that the Goldfield Consolidated company is producing less than 1000 tons of ore per day from seven shafts, while the Douglas Island mines are producing several times as much from four or five shafts.

Orebody Expands Upward

There are two known periods of fracturing, the first producing the fractures which localized the lode quartz, the second producing those which localized the ore within it. It seems that the movement of the second followed the same paths as the movement of the first, and was a renewal or continuation of it. The strains which induced the lode faulting, and of which the Columbia Mountain fault is the most clear cut manifestation, were effective over a period which comprehends the periods of solfataric alteration and of ore deposition.

The only useful generalization I can make concerning the reasons why the gold was precipitated where we now find it is derived from the fact that the ore locality expands upward. There is no known coincidence, for the example, between ore and cross fractures. And the fact that the ore locality expands upward forces me to the conclusion that superficial conditions, those of relatively low temperatures and pressures, were the conditions which caused the gold to deposit. This conclusion is most unsatisfactory to the miner; for he would not only have his orebodies prolonged downward, but he would also possess knowledge of some easily recognized sign, indicating definitely the whereabouts of ore.

We have seen that feeders extend beyond the limits of orebodies as seams carrying some gold, but often barren. There is no warrant, under the hypothesis of precipitation which we have been just now considering, for the belief that even the barren parts of the seam were not at one time the paths of ore mineralizers. And I can conceive of an opening not over a few feet long and perhaps now entirely devoid of gold, as having constituted the channel for the mineralization of the whole district. In other words, the absolute disappearance downward of a Goldfield orebody, or, eventually, of all the goldfield orebodies, is not to be regarded as an unsolvable mystery.

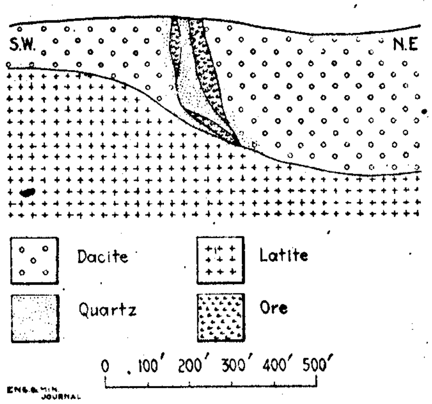


Fig. 6. Generalized Vertical Section through the Combination

The classification of Goldfield as belonging to the group of gold-ore districts having relatively shallow precipitation brings up the large contrast between the new gold deposits and the old, those of Tertiary age, like Goldfield, Cripple Creek, and the Comstock, whose ore expands upward and is high grade, and those of pre-Tertiary age, like Douglas Island and the Mother Lode of California, whose ore occurs without any known dependence on depth, and is low grade. So far, there is little knowledge concerning the precipitation of gold which is of use in mining. Perhaps this large contrast, which was long ago noted, may, at some future time, serve as a basis for such knowledge.

The ore was everywhere localized by fractures which constituted channels for the passage of ore mineralizers. The only materials having sufficient brittleness to afford such channels are quartz and fresh rock. But fresh rock occurs but rarely in the Goldfield district, and the quartz, which in its fractured condition, Ransome vividly likens to a sponge, is the only possible ore container. But why, then, do certain quartz bodies, situated near the western edge of the area of alteration, monopolize the ore?

Fractures, the Third Invariable Condition of Ore Occurrence

I do not believe that these ore-containing quartz bodies differ essentially from the hundreds of barren ledges lying further to the east, or that they possess any intrinsic quality which renders them more hospitable to ore minerals. But, as is probable, it happens that they were fractured in such a way that channels connecting with sources of gold were opened up within them. And these fractures are to be regarded as the third invariable condition of ore occurrence.

Ransome concluded that the solfataric alteration of the rocks was chiefly an acid alteration, effected by the accession of sulphuric anhydride and sulphur, and the removal of lime, magnesia, soda and some potash, and that probably the quantity of silica and iron added was small, the original silica of the rock being sufficient to furnish the silica for the now existing quartz, and the present pyrite gaining its iron from the broken down iron-bearing minerals.

"Open-space" quartz, such as exists in enormous quantity in the Comstock and in the veins of the California Mother Lode, has, in Goldfield, but a meager development. In fact, the largest body of such quartz which I have seen in Goldfield measures not over two inches in thickness. Now, the ore minerals are chiefly an "open-space" filling, and only subordinately a metasomatic deposition. As in Cripple Creek, it is cracks, and not the walls of cracks, which carry gold. And, as in Cripple Creek, this gold was not greatly diluted during deposition by simultaneously deposited gangue materials. Perhaps the smallness and paucity of the cracks had something to do with the richness of the ore.

Ore Younger than the Quartz Lode

General considerations enable us to dismiss the possibility that the "open-space" mineralization is older than the replacement mineralization—in other words, that the ore is older than the quartz in which it lies. The possibilities presented, then, are: (1) The quartz lode and the ore were of simultaneous deposition. (2) The ore is younger.

The first possibility regards extensive silicification as a property of ore mineralization. It explains the general parallelism of ore and lode by the supposition that the lode was formed with the ore and that the ore remained chiefly within cracks, while the silicifying mineralizers, separated out by osmosis, wandered off into the containing rocks. It will be noted that this is the hypothesis usually employed to explain the limitation of ore minerals to cracks in the solfatarically altered rocks of Cripple Creek.

To this hypothesis there are serious objections. I have seen a number of ore pebbles composed of a hard breccia of quartz fragments and carrying external crusts of ore minerals. Here, ore deposition was plainly later than silicification and cementation, and there is nothing whatever to indicate that the ore minerals are not primary. Moreover, the large facts of ore distribution constitute an argument in the same direction. As we know, the locality of softened rock coincides broadly with that of silicified rock; their coextensiveness suggests strongly that softening and silicification were contemporaneous. But the locality of ore occurrence is vastly smaller than that of silicified rock, and is in no sense coextensive with it.

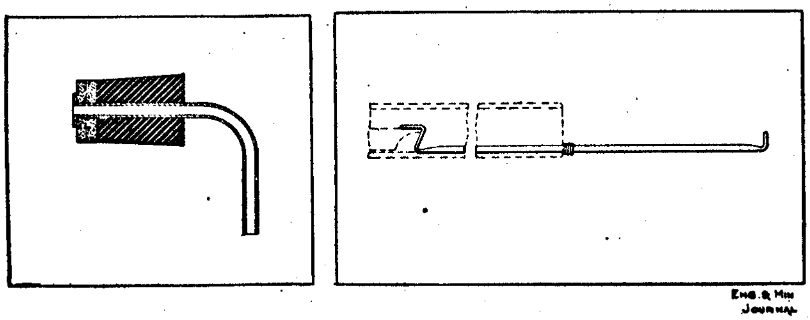
Ore mineralization, then, was not a general accompaniment of silicification; the presumption is that it belonged to a distinct period. And, again, the probability of an osmotic separation of the sort which would account for the sharp boundaries between ore and waste, is vaguely understood. No such separation has ever been conclusively proved to have taken place in ore deposition, and to assume that it had taken place here would be rash. These considerations being taken into account, together with the altogether pertinent fact that the ore minerals inhabit cracks in the quartz, it must be concluded that the second hypothesis is the correct one.

An interesting fact in connection with the production of coal in the United States, from figures compiled by the U. S. Geological Survey, is that in each successive decade the output has been practically doubled.

Rapid Determination of Sulphur in Roasted Blende

The following method is suggested by C. C. Nitchie as a rapid method for the control of blende roasting (*Journ. Ind. Eng. Chem.*, January, 1912). It is stated that results can be obtained in 10 min. from the time of sampling, hence a charge of roasted ore can be analyzed and its exact disposal determined, before it is put into storage. The method depends upon heating the blende in a current of air, absorbing the oxides of sulphur evolved in standard alkali, and titrating the excess.

In blende roasting, some of the original sulphides are left unchanged, while a small part of zinc, some of the lead, and all of the lime are converted to sulphates. On heating the roasted ore in a current of air to a bright red, all of the sulphides are oxidized, giving metallic oxides and SO_2 and SO_3. Sulphates of zinc and lead are decomposed, but calcium sulphate is not, at the temperatures ordinarily reached. However, as the results are to furnish an index as to the completeness of the roast, and as calcium sulphate is not decomposed in roasting furnaces, the results obtained by this method, which may be termed "false sulphur," are the sulphur which, under proper conditions, might have been eliminated in the roast.



RAPID DETERMINATION OF SULPHUR

In the determination there is a copious evolution of zinc-oxide fume as long as any sulphur remains unoxidized. The cessation of this fume furnishes an accurate index to the completion of the reaction. This fume is not appreciably dissolved by the standard alkali, and hence does not vitiate the results. Phenolphthalein is used as indicator, as it is sensitive to both sulphurous and sulphuric acid.

Combustion is carried on in an electric tube-furnace, with a fused silica combustion tube. The ends of the tube are cooled by wrapping them with strips of cotton gauze, which dip into distilled water. Tap water should not be used as it forms a crust of salts over the gauze, decreasing the cooling effect. To avoid burning the rubber stoppers in the ignition tube by radiant heat, these are protected by disks of asbestos, as shown in the illustration, that are held in place by upsetting the ends of the glass tube.

A convenient means for introducing the boat without the necessity of looking to see that it is not overturned, is also shown in the illustration. The device is made of heavy, not easily corroded wire (such as nickel). One end is flattened and so bent that the end projects over the end of the boat, and is in contact with it when both boat and wire are resting on the bottom of the combustion tube. The other end is bent at a right angle to make a hook for withdrawing the boat, and also to indicate when the rod is in the proper position to keep the boat upright. A notch is filed on the nickel wire, or a fine wire wrapped around it as a guide at the point which is flush with the end of the tube when the boat has been pushed to the middle of the tube.

The solutions are simply standard sulphuric acid and sodium hydrate, and the most convenient absorption vessel was found to be the Murray potash bulb.

The car of blende, as brought from the kiln, is sampled in two places by a spear sampler; this sample is cut down with a riffle to about 50 grams, and ground with a few turns of the muller in a Buck's mortar. Fine grinding is undesirable, as it prolongs the time necessary for the analysis by restricting the free circulation of air through the ore.

Details of the Combustion

A measured quantity of standard alkali, seven to 10 c.c. will usually suffice, is run into the absorption bulb, and diluted sufficiently with distilled water to a volume that will bring the solution into the fifth bulb when the air current is passing. The bulb is then attached by a bent glass tube to the exit end of the furnace.

One gram of ore is placed in a combustion boat and introduced into the furnace, which has already been heated to about 1000° C. A moderately rapid current of air, freed from carbon dioxide by caustic potash or soda lime, is passed through the apparatus until the sulphur is completely driven over into the alkali solution. This usually requires about six minutes. When the zinc-oxide fume has completely disappeared from the large bulb of the absorption vessel, the air current is stopped. The absorption vessel is disconnected, washed out into a beaker, phenolpthalein added, and the solution titrated. If total sulphur is desired, add to the "false sulphur" in per cent., four-sevenths the percentage of lime.

Attempts to use the method for the determination of sulphur in raw ores have led to low results, either from failure to absorb the larger quantity of sulphur gases or from condensation of part of the sulphur trioxide on the cooler portions of the tubes.