UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 4, No. 10, pp. 177-199 - 1905 - ANDREW C. LAWSON, Editor

THE STRUCTURE AND GENESIS

OF THE

COMSTOCK LODE

BY

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CONTENTS.

STATEMENT OF THE PROBLEM.

In these days of rapid advance in our knowledge of the genesis of ore bodies, it becomes necessary constantly to test old ideas by new conceptions. Particularly does this apply to our recent ideas on secondary enrichments of ore deposits. The mining world is awaiting eagerly more exact knowledge on the part of geologists, that the cost of locating valuable ore bodies and developing them properly may be reduced. The structure of the Comstock lode, and the genesis of its ores, have been treated by several investigators, but even yet, many of the vital questions connected therewith are unsettled. The somewhat overdone tendency to make every ore deposit correspond to a "type," and to regard much, if not all, as already "having happened," has been productive of considerable error. Fortunately, with our ever widening view, these marks of immature science are disappearing. The Comstock is yet largely an unsolved problem, withal we know much about it, and the following notes contributed to its solution are the result of numerous short trips to the lode while the writer was engaged in other work.* The peculiar bonanzas of Virginia City have never been satisfactorily accounted for, nor the form of the lode as a whole. This paper is offered as a slight contribution to the study of ore deposits, and on account of the immediate bearing of its contents upon practical mining matters, it is issued at this time.

EAST-WEST FAULTS.

There is a much greater development of east-west faulting than has been noted by previous observers. These faults are of the utmost importance, both in the structure of the lode and in

* The author's acknowledgments are due to Mr. James McKinty and Mr. Thomas McCormick, superintendent and foreman, respectively, of the C. & C. mine, for their aid in obtaining deep mine waters; Mr. E. E. Everett for aid in obtaining mine waters and rock specimens; Mr. M. W. Fox, and Mr. Frank Higginson, general manager and superintendent, respectively, of the Hale and Norcross; and particularly to Mr. G. McM. Ross, whose great interest in these matters lies at the bottom of this short paper. Mr. Ross was until recently superintendent of the Ophir and Mexican mines. The author wishes also to state his indebtedness to former publications upon the Comstock, particularly Becker's Monograph and King's Survey of the Fortieth Parallel. These works have been freely consulted on points not now to be determined in the mines.

Becker's Atlas should be consulted for maps, etc.

the genesis of the ores. Their importance to the lode lies in the fact that they have most to do with the notable short length of the main fissure. Their importance in regard to the ores lies in the fact that they have caused the blocking out of the wall rocks with the resultant opening to mineral solutions. These points will be discussed later. Becker* has noted the presence of such faulting, but only in a general way, and as of little importance. He says (p. 181) that the topography is due chiefly to faulting, "for on the Sutro tunnel section, at least, there is evidence of but slight erosion. * * * The ravines which furrow the range are not therefore the results of erosion, but of faulting." And again (p. 184 *et seq.*) "To the north and south of Mt. Davidson the evidences of faulting diminish (north-south faulting is meant). From the Overman far into the Sierra Nevada claim, a distance of two and one-third miles, the amount of fault has been great, and the indications unmistakable. Beyond these points the disturbance of equilibrium has been to some extent adjusted in a different manner. This is partly indicated by the union of the andesite fields, which are separated near the center of the lode by diorite. Toward the ends of the lode the dynamic action seems to have been distributed in part by the forking of the fissure and in part by the *formation of east and west cracks.*" According to Becker, these same east-west faults have their downthrow to the north. Practically nothing more is written in the monograph of Becker concerning these movements. But even now, with almost none of the old workings accessible, their large development is well shown. The most noteworthy examples are as follows:

Mexican Fault.—In the Mexican ground, on the Sutro tunnel level, a very strong east-west fault was followed into the diorite of Mt. Davidson, and east into the hanging wall block for several hundred feet. No ore was developed, and the work was abandoned. Pyrite was very abundant, however, in the crushed zone. This fault was nearly vertical, with a slight inclination to the north. The throw, from all appearances seen, as striations, etc., was down to the north, making a normal fault. This line of mo-

*G. F. Becker. Monograph III. U.S.G.S. "Geology of the Comstock Lode."

tion is directly in line with Ophir Ravine, and no doubt was the main cause of its formation, as noted in general by Becker, quoted above.

Bullion Ravine Fault.—Bullion Ravine is likewise determined by a fault plane, in this case shown largely by stratigraphic and physiographic grounds. A new geologic map is necessary to show this fully, as that of Becker * is in error at this point. In the first place, this rocky ravine shows plainly that erosion has had nothing to do with its formation, for its bottom has never been occupied by a stream. Becker notes many times that the erosion of the region has been little or nothing since the vein formation, and this is merely a case in point. Moreover, in the second place, here is a structural discordance between the walls of the ravine. The north wall is solid diorite to the summit of Mt. Davidson. The south wall is diorite farthest east, but andesite a short distance west up the ravine. The contact between the two rocks appears to be in the exact center of the ravine, but is obscured by surface wash.

Other Ravine Faults.—The ravine leading up to Mt. Butler, and Crown Point Ravine farther south, have not been examined in detail, but they partake of the characteristics of the others: typical fault ravines. Becker, though noting this, fails to give supporting evidence because he attached no importance to their structure. Such evidence is plentiful for all these east-west gulches, the most important of which is as follows:

1. The erosion of the country has been very little since the faulting, so that we are driven to look for other causes for the formation of the topographically striking ravines. In the case of Bullion and Ophir Ravines, at least, this cause has been shown to be faulting. Becker's reason for a lack of erosion seems to lie in the close similarity of the contours of the actual faulted surface with the theoretically deduced one. Further reasons, and conclusive proofs, are: (1) there is little or no removal of the thoroughly decomposed country rock near the lode; and (2) the present surface of the lode, or its outcrop, is that of the original lode apex, formed under practically no pressure from above and

* G. F. Becker, Mon. III, Atlas, U.S.G.S.

not yet removed by atmospheric agencies. The cross-section of the upper portion of the lode, figure 1, shows this structure.

2. There is no stream worn material of any sort, except very locally, in these ravines, nor any outside their mouths where a deposit would take place by stream action. The whole region is remarkable in the lack of all such material.

No faults from Bullion Ravine in the hanging wall underground have been seen, because this area is not accessible. But on the surface, east of the lode, there are many very well defined east-west faults, some of which are filled with calcite. A few have been prospected and considerable ore extracted. The ridge running east from Bullion and Crown Point Ravines is a locus of these movements.

Cedar Ravine and Cedar Hill Cañon—These are the large gulches on the north end of the lode. Cedar Ravine is due to the surface effects of the east-west motion exposed underground in the Sierra Nevada mine, as is Ophir Ravine the surface effect of the fault shown in the Mexican mine. Cedar Hill Cañon is rather beyond the limits of the lode, yet deserves mention because it is the sharpest cut of all the fault ravines, and, like Bullion Ravine, shows the faulting by the stratigraphic relations of diorite and andesite. In both instances the andesite abuts against the diorite on a plane which occupies approximately the center of the gulches. In Bullion Ravine the andesite is south of the diorite; in the northern fault cañon, the andesite is north of the diorite. This andesite is *Becker's "earlier hornblende andesite," which has been shown to be identical with the porphyritic facies of the diorite mass.† Hence, an abutment of one of these rocks upon the other indicates a fault plane.

There appears even yet to be a doubt in the minds of some geologists, for instance, Lindgren,‡ as to the correlation of the Comstock rocks. The evidence for this correlation is, of course, of two kinds: (1) microscopical, and (2) macroscopical, includ-

*G. F. Becker, op. cit.

†Hague and Iddings, Bull. No. 17, U.S.G.S. "On the Development of Crystallization in the Igneous Rocks of Washoe Co., Nevada.

‡W. Lindgren, in one of his numerous papers, states that he believes the Comstock rocks to be separate flows.

ing both field and laboratory work. The microscopical evidence of Hague and Iddings needs corroboration on but one possible point—that of the undoubted occurrence of fresh augite as the *chief* ferromagnesian mineral in the diorite. The field evidence, however, seems to be insufficient regarding the diabase and diorite. The present writer, through late mining work, is in possession of the facts necessary to prove beyond the shadow of a doubt the conclusions of Hague and Iddings. The Hale and Norcross tunnel into Mt. Davidson, just north of Bullion Ravine, has brought to light these facts, and also a number of structural facts of the most vital importance. The structures shown will be discussed later, and a note on the rocks will be placed near the end of this paper.

Forks of Comstock Lode.—The main forks of the Comstock lode, both north and south, are quite similar in their action on the formation of the fissure as seen to-day. Of the Sierra Nevada fork, which strikes nearly east and west, the writer can say nothing, for so much of the old ground is not open. However, the east-west slips are well shown underground in the present workings, and this portion of the lode country appears to be a locus of these movements. The large southeastward bearing "fork" of the lode which runs toward Silver City, has some peculiarities which deserve mention. In the first place, this so-called branch is not a mere fork of the lode, but as a fault continues west of the lode into the mass of Mt. Davidson west of the summit. Bullion Ravine exhibits this fault in the best manner. As already noted, the south wall of the ravine is diorite for a few hundred yards west up the gulch, when andesite appears from the bottom of the south wall clear to the top. The topography also shows the change, the diorite portion being steep and precipitous, while the andesite is smoother and of more gentle slope. The transition from one to the other is abrupt. Some prospecting has been done along this line and some ore found. The gangue in the Silver City portion or "fork," as of a few of the east-west veins east of Bullion Ravine, is largely calcite. Granting the identity of the rocks as set forth in the work of Hague and Iddings, this difference in gangue mineral from the silica of the lode proper

can be accounted for, in the most probable way, by assuming a difference of age.

Fault in Andes Mine and Central Tunnel.—The Andes mine workings and the Central tunnel show many east-west faults. There is a great complexity of these in the surface workings, as is to be expected in the great lode. The largest one in the Andes cuts off sharply one of the bigger quartz bodies between the horses of diabase. Others, of less extent, but still of some size, cut across the vein proper, and act as channels for mineral solutions, as will be mentioned later. These motions are shown by clay and rolled pebbles of quartz. The east-west movements in all the surface workings are characterized by identical features. A very peculiar action is now taking place along one of these cross fractures in the Central tunnel, where there is little circulation of air, characterized by the deposition of pyrite from an acid solution.

BONANZAS.

Virginia City.—The formation of the Virginia City bonanzas is peculiar, and has never yet been concisely presented. The present developments in mining work have thrown much light upon this question of genesis. In the Virginia City portion of the lode the ore occurs not in the main fissure, but in openings or "veins" in the hanging wall, which occupy nearly vertical positions (see figure 1). These "veins" are more nearly allied to gash veins than to what are usually called "fissure veins." The "secondary vein" now so productive in the Ophir ground, has brought to light some valuable and interesting facts. (1) It has been found only in the lower mine levels, either as a mere fault zone or a productive deposit. (2) From the lines of motion preserved finely in the clay gouge, the relative movement of the walls is seen to have been nearly horizontal, whether north or south the writer is not able to state definitely. From the parts of the "vein" observed, however, chiefly on the 2050 level, it seemed probable that the motion was to the south for the east wall, dipping downward about four degrees in the same direction. This corresponds to the view that the vein itself is due to a pulling apart of the rock mass, causing the greatest openings to

the north, in the concavity caused by the bending of the "vein" to the east at the north end. This northeastward swing causes the secondary opening to become nearly parallel to the Sierra Nevada fork, as shown diagrammatically in figure 2. The thick-

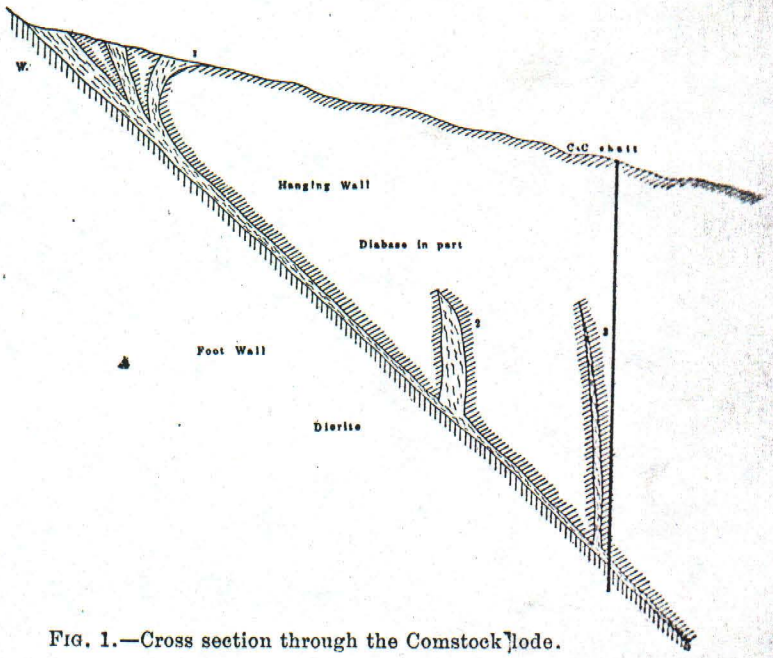

FIG. 1.—Cross section through the Comstock lode.

ness of the ore body within this opening increases with depth up to the present time of working, and some very rich ore is being extracted. Exact distances and figures cannot be given, on account of the methods of mining now in vogue. The "vein" has been, and is, productive up to the 1800 level of the C. & C. mine and down to the 2250 level now being worked. The ore is not evenly distributed, but is in more or less well-defined chimneys or shoots, connected by material of too low grade to be worked. The form of this secondary vein, then, is a nearly vertical fissure about parallel to the main lode and east of it. In portions of this vein, particularly where opened best in stoping, a dip to the east is present.

The lode at the surface shows an arrangement of vein filling and ore in every way due to the same causes which produced the

secondary fissures at greater depths. The "west vein" and the "east vein" at the surface have been carefully described many times by previous observers,* and the fact that only the "east vein" carried values has caused much discussion. This "east vein" is merely the gash which reached the surface, thereby ap-

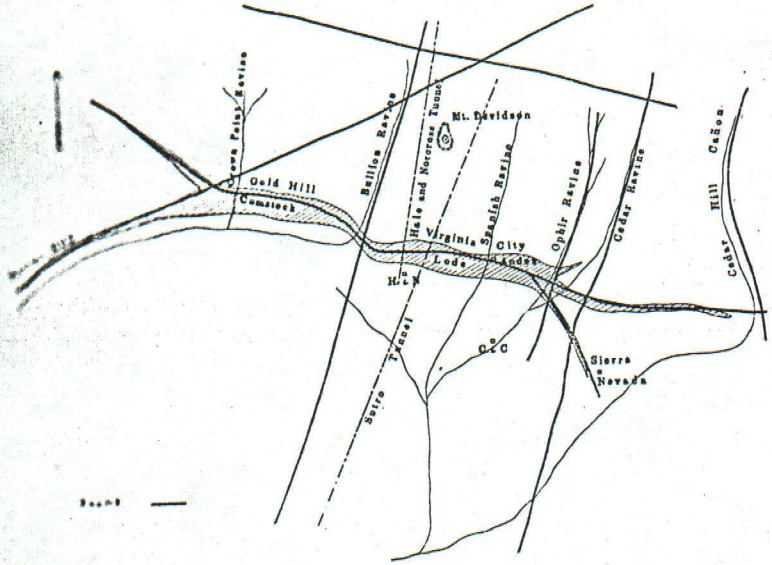

FIG. 2.—Ground plan of Comstock lode, showing disposition of faults.

pearing as a vein occupying a fault plane and resultant fissure. These three gashes—the surface "east vein," the famous bonanza, and the "vein" now being worked, all have an identical origin. Their formation lies in the fact that the lower part of the hanging wall block has settled more than the upper, relative to the foot wall, and has been torn apart by the stresses developed. This form of ore deposit is rather new, and because of its evident importance deserves a distinctive recognition. The term "gash vein" is not suitable, obviously, and the name "rift vein" is suggested to cover the structure.

Gold Hill.—The bonanzas of Gold Hill are found in the lode proper, near the east wall, and east of the low grade quartz. The

* G. F. Becker, op. cit. Clarence King, "Survey of Fortieth Parallel," Vol. III. John A. Church, "The Comstock Lode—Its Formation and History."

differences in the form of the bonanzas in the two portions of the Comstock lode have been noted by other observers. In Becker's monograph,* von Richthofen is quoted as writing: "The ore is distributed in a different way in the northern and southern parts of the vein. * * * In the northern part the ore is concentrated in elongated lenticular masses of which the greatest axis is not far from vertical. * * * To the south the ore is concentrated in continuous sheets, the principal one of which is very near and parallel to the eastern wall." This difference in the form and occurrence of the ore bodies is a very important matter, both from a scientific and an economic standpoint. This subject, and what grows out of it, is the main reason for the writing of this short paper, for a proper view may increase the life and output of the mines very materially.

One peculiar bonanza occurred in the Gold Hill group, in the Yellow Jacket mine. The explanation of this, as of the others, will be given later.

HALE AND NORCROSS TUNNEL.

The structures shown in the Hale and Norcross tunnel will be mentioned together, for the sake of simplicity. This tunnel, running N. 75° W., enters the slope of Mt. Davidson at the Hale and Norcross shaft (see figure 2). At a distance in of 1,080 feet the footwall of the lode is reached, the so-called "black dyke." 1. Proceeding in, at a distance of 3,720 to 3,750 feet, appear approximately vertical slips striking N.W.-S.E. parallel and in line with the Silver City lode as shown on the surface. A second well developed slip parallel to these occurs at a distance of 4,550 feet in from the mouth. 2. In nearly all portions of the tunnel, but particularly between the lode and 3,500 feet in the tunnel, and from 4,500 feet to the end (5,085 feet on Feb. 12, 1905), are seen slips parallel to the Bullion Ravine fault; that is, approximately parallel to the course of the tunnel itself. These indicate unmistakably evidence concerning the existence of the Bullion Ravine fault underground. 3. At a distance in the tunnel of 4,908 feet occurs a very strong vertical north-south fault. The east wall is the diorite of Mt. Davidson, and the west wall

* G. F. Becker, op. cit., p. 17.

is the same rock which forms the hanging wall of the Comstock lode, the diabase of Becker. This rock continues to the face (given above), and no doubt shades into augite andesite farther west, just as in the east country. Thus the diorite of Mt. Davidson is terminated east and west by identical structures. No doubt tunnels north and south would develop the same conditions on the other two sides, as indicated by the surface structures. West of this west fault just noted, the prevailing slips are perpendicular to the tunnel and dip to the west, in contradistinction to the eastward dipping slips near the Comstock.

The west diabase, as it will be called, now shown in the tunnel, is much fractured and filled with veinlets of pyrite. Some films of galena and sphalerite up to one-eighth of an inch in thickness also occur fifteen feet west of the fault. These gave some values by assay.

DEEP ORES AND WATERS.

The ores are doubly interesting from that fact that their deposition still continues, due to faulting opening up new fissures and fractures, and from the fact that the mine waters are, for such waters, rich solutions yielding very positive results to fire assay methods. The ores are moving in two ways: upward and downward.

That the ores have moved upward at more than one time has been noted best by Becker.* He writes (page 219): "In the great California and Virginia bonanza several streaks or veins of very rich black silver ores, said to be largely stephanite, occurred. These were separated from the surrounding quartz very sharply, as if of later origin." Again (page 221) he writes: "What I have seen * * * leads to the belief that these rich concentrations were of later origin than the rest of the ore. The quartz in the C. & C. was almost everywhere a crushed powdery mass, while the thin and persistent veins of black ore running through it were very solid. A somewhat similar relation seems to have existed near the croppings, and it is not impossible that these ores were formed at the expense of others of the more usual kind at a later date, and that they occupy spaces opened in the ore masses by faulting action."

* G. F. Becker, op. cit.

The writer had hoped to present even more conclusive evidence of successive deposition and its recency, but owing to the fact that the lowest mine workings are not open to outsiders, this became impossible. However, such evidence as already possessed is as follows:

In the ore bodies opened within the last year on the "secondary vein" now worked, some pertinent facts presented themselves. The finest specimens of ore show often very perfect crystals of stephanite and argentite coating, or wedged between, quartz crystals. Coating one side, the downward side, of all the minerals, is a thin layer of calcareo-siliceous material. Below the surface crystals of ore and quartz is a layer of quartz, resting in turn upon a second layer of calcareo-siliceous matter. This shows below it a second layer of ore, resting upon quartz crystals, and so on, the series often repeating itself several times more or less perfectly. In that portion of the ore occurring in the lower depths, from which the water has been drained but a short time, the surface layers of ore, quartz and calcareo-siliceous matter showed clear and fresh, while on standing in the open, or in the higher portions of the vein, the same minerals appeared dusty and old. In some of the vugs in the lower portion of the ore body, quite a number of small but perfect rhombohedra of calcite were found; also, as noted by Becker, old fractures in the ore, caused by faulting movements, are cemented with quartz and ore. In the ores now worked, however, the motion appears to have been a pulling apart, for brecciation, though present, is rare, and the two sides of a cemented break are usually fully complementary. This process of successive deposition is not limited to the Virginia City portion of the lode, but is found quite well developed in the Gold Hill mines, and in the calcite gangue of the Justice ore body.

Further uncemented fractures present themselves as indicators of motion up to the present time, since the withdrawal of the waters by the mine pumps. The great volume of water still entering the lower workings also contributes abundant proof of fissures kept open by late motion, for the lode proper, where cut by the shaft, is reported to have been completely filled with quartz.

Analysis of Waters.—The ore now being mined below the 2150 level, which was all below water level within a few months, shows the same conditions, with the surface minerals in the freshest possible condition, precisely as if just deposited from solution. A notable fact of these lower deposits is the greater proportion of gold to silver than was found in the ores above. On the 2050-foot level and below, considerable free gold was found. The actual process of deposition cannot well be watched, hence as the best substitute the deep waters from the 2250 level of the C. & C. shaft were analyzed and assayed, to determine if they were able to do such work as indicated. They are exactly suited to this, as the following facts will show. The water is the typical deep water of the Comstock lode whose temperature has reached as high as 170° F., and is always over 116° F.:

ANALYSIS OF MINE WATERS.*

	Grams per liter.
SiO_2	0.1334
Al_2O_3	.0025
Fe_2O_3	.0091
CaO	.1404
MgO	.0097
SO_4	.3957
Cl	.0190
CO_2	.0150
K_2O	.0643
Na_2O	.1765
Total solids	.9656

Assay of Waters.—From an evaporation of 10 liters of the water, the following assay values were obtained. This work was most carefully done, and the results are accurate. The gold buttons obtained by parting were measured by a microscope and their weight calculated. This result may therefore be a trifle high, because of the possibility of the gold being slightly porous. The litharge used was remarkably pure, a number of test assays on 100-gram charges failing to show the merest trace of a button under the highest powers of the microscope.

Silver.....2.92 mg. per ton of solution
Gold.....0.298 mg. per ton of solution

*Analysis by N. E. Wilson, Professor of Chemistry, University of Nevada.

The analysis of the water showed it to be an alkaline sulphate and carbonate solution containing a large amount of lime. The presence of chlorine is important as affecting the gold in solution. The CO_2 determined is low, for on standing, some of this gas is given off and the silica separates out in sufficient amount to render the water milky. The writer has been unable, for stated reasons, to test the water in the mine. The jugs of water stood for from 48 to 64 hours before testing, hence the figures for the carbon dioxide need considerable correction. On evaporating the water and moistening the residue, a strong alkaline reaction is obtained by litmus paper.

SURFACE ORES AND WATERS.

The ores are moving downward by the leaching action of the acid surface waters. In this way they are extracted from their containing rocks and redeposited below. This process in the past has produced the striking "nodular" ores of the Andes mine, noted by King* as occurring just below the level of ground water. These ores are now in their turn being attacked and again being carried below. A striking example of the ore deposited by the vadose waters was exposed on one of the levels of the Andes mine. The presence of east-west slips has already been noted as occurring here, and one of these, dipping south 60°, had opened sufficiently to allow the free circulation of water. The slip had cut across all other rocks, vein and country, and was filled with about two inches of solid coarse black sulphides of lead and silver. This small sheet of ore pinched out toward the bottom of the drift, but broadened above. The grain of the ore, and general characteristics of ratio of lead to silver, etc., were all different from the ore which occurs below, deposited from the deep circulation. The nodular ores consist typically of nodules ranging in size from that of a pea up to a foot in diameter, and composed of rich black sulphide ore in a matrix of fine crystals of quartz. Each nodule is completely surrounded by barren quartz, which at times may penetrate the nodule along later cracks. These quartz crystals are built upon the nodules as centers, giving them a radial arrangement.

* Clarence King, "Survey of Fortieth Parallel," Vol. III.

All the facts relating to these peculiar ores tend to confirm the view of their deposition resulting from the intermingling of oxidized surface waters with deep alkaline unoxidized solutions. They are known to occur nowhere else on the lode in any mine workings, although the exploration within the croppings is very little in amount.

The acid surface waters which are now doing so much work, have covered the walls and cross-cuts of the Andes mine with from six inches to a foot of sulphates containing traces of gold and silver. The chief salt is the magnesian aluminum sulphate, with also large admixtures of iron and copper, which results in a remarkable variety of colors. The workings of the Central tunnel likewise shown these sulphates, but in general the circulation of air is too rapid to allow of their great formation except in some favorable localities. The composition of these salts is shown as an average in the water analysis following. In the Central tunnel in one particular spot, where the surface waters are not fully oxidized, ferrous sulphate and pyrite are being deposited at the present time. Some sulphates are being formed here in delicate needle-like crystals containing a large amount of the ferrous salt. Bright, well-formed cubes of pyrite and some few dark sulphides, too small in amount to admit of testing, occur below and within the sulphates. Not infrequently a little crystal of pyrite tips a needle of sulphate where the solution is plentiful. Also, almost solid masses of the sulphide are found within the wall in the partly decomposed country rock. The water is descending along an east-west slip which dips to the south. The clay, or clayey rock, upward along this slip is full of pyrite, but this mineral is heaviest near the wall of the drift, where the solution is able to cover more ground. The clays of the upper portion of the lode are all found to contain well formed but small crystals of pyrite containing some value. There is probably but one process responsible for all this, and a possible reaction of the surface waters to produce such a result may be expressed as follows:

$$FeSO_4 + 2H_2SO_4 + 7H_2SO_3 = FeS_2 + 8H_2SO_4 + H_2O.$$

This reaction is, of course, possible only when there is an

insufficient supply of oxygen, as occurs locally in this part of the Central tunnel.

The water surrounding the sulphates and pyrite being deposited, is strongly acid, the most so where the pyrite is heaviest. As the wall is worked into, the acidity becomes perceptibly less. The ferrous sulphate appears to exercise the necessary protecting influence over the pyrite to save it from attack by the free acid or further attack by the small amount of free oxygen present.

Analysis of Waters.—The analysis of the vadose water, from Central tunnel, taken from a dropping stream out of the wall on the lower level, is as follows:*

	Grams per liter.
SiO_2	0.6160
Al_2O_3	18.2140
Fe_2O_3	7.1786
Mn_3O_4	1.2500
CaO	1.7400
MgO	10.8108
CuO	0.1850
SO_3	70.1154
Cl	0.1276
H_2O	trace
Na_2O	0.7209
Total solids	110.9583
Free H_2SO_4	125.0804

The remarkable properties of this water are evident. Silica is noticeable in amount, in spite of the strongly acid solution. The salt is seen to be essentially a magnesian ferric aluminum sulphate, with lime, copper and manganese. These mine solutions vary, and the writer has taken from the roof of some of the old stopes stalactites of quite pure copper sulphate. The water analyzed was a fully oxidized solution; the water depositing the pyrite is only partially supplied with oxygen.

Assay of Waters.—The assay of this vadose water gave the following results: 250cc. portions were used for each test.

Silver.....188.0912 mg. per ton of solution
Gold..... 4.1528 mg. per ton of solution

It is necessary again to note the fact that some of the east-west veins which exist east of Bullion Ravine on the line dividing

* Analysis by N. E. Wilson.

the Virginia City portion of the lode from that of Gold Hill, are filled largely or wholly with calcite gangue. The same mineral acts as vein-filling in the Silver City lode. Becker * favors the view that the difference in gangue mineral between the Silver City lode and the main vein, is due to differences of country rock. But as the calcite veins exist in the augite andesite east of Bullion Ravine, this idea cannot hold. On the fact, however, that the two lodes are due to different faults, a more probable conclusion is that the deposits are of different age. The proof of this lies in the examination of the point where these two lodes intersect, which is not now possible. Published reports and maps are insufficient as a basis for judgment.

A further fact of importance regarding the lode, in the Virginia City portion especially, is that the width of the vein is often little or nothing in the lower levels. Moreover, the west wall is not well defined in all places, because of a complexity of slips in the west country. This portion of the ground in all the lower levels has not been thoroughly prospected, in spite of the many thousand feet of mine workings.

ROCKS OF HALE AND NORCROSS TUNNEL SECTION.

A full report of this section is not yet ready, nor would it be proper at this time before the tunnel is complete. A full set of rock specimens, taken every fifty feet, and oftener over important places, is now being collected for the writer. However, the importance of the main facts concerning the rocks within Mt. Davidson is too great to allow their complete reservation at this time. These facts are briefly as follows:

1. The Hale and Norcross tunnel (see figure 2) strikes the lode footwall at 1,080 feet in from its mouth. The first wall rock encountered in the foot is the well known "black dyke," of decomposed basalt,† a few feet in width. Beyond this, in to a distance of 1,270 feet, is a fine-grained, dark rock looking much like a fresh augite andesite. In the Mexican ground, in the crosscut tunnel mentioned above (page 3), the same rock occurs east of the lode, shading into diorite to the west. Under the mi-

* G. F. Becker, op. cit., p. 220.

† Hague and Iddings, Bull. No. 17, U.S.G.S.

croscope the rock is seen to be an augite rock of a texture between an augite andesite and a diabase, yet which in spots is that of a fine-grained augite diorite. The augite is fresh, and in more or less irregular grains or in well formed crystals, with high birefringence, very faint pleochroism, and an extinction angle of from 40° to over 50°. The feldspars are well formed, and crystallized at about the same time as the augite. They all show extinction angles of over 20°, and are labradorite. Some few flakes of biotite and grains of quartz are also present. At 1,200 feet in there occurred what appeared to be a thin dyke of diorite one-half an inch wide, intrusive in the dark augitic rock. No well defined boundaries were shown, however. Farther search showed many more such dykes at 1,250 feet, of apparently the usual pinkish diorite, intrusive in the dark rock. The microscope revealed the fact that the two rocks differ only in coarseness of grain and alteration of feldspar, and that the change from one to the other is gradual. The pinkish diorite was thus found to be an augite rock with some of the large augites altered to uralite, but identical in all particulars but grain with the dark-colored stone. The dyke at 1200 feet seemed to show that some motion took place in the mass when still plastic, as very often happens in igneous magmas, for the transition from the fine to coarse grain was more sudden than in the small dykes at 1250 feet. Beyond 1250 the ordinary type of pinkish, coarse-grained diorite comes in gradually. The microscope proved this to be a true augite rock also, with many crystals of fresh augite, and more such changed to uralite in part, and partly to chlorite, epidote, and magnetite. This pinkish rock continues on until at 1358 feet a small mass of diabase occurs, from six to ten feet wide along the tunnel. One side of this diabase is bounded by a slip and some brecciation; the inner side passes into diorite very gradually.

Again at 2650 feet, and at 3725 to 3760 feet, diabase occurs, in the latter case particularly, shading beautifully into diorite by all possible gradations. Specimens taken here are either diabase, or diorite, or both, as one may choose to call them. And the rock is all augitic, though none of this mineral is wholly fresh. The rock is much fissured and jointed, so that the alteration of the minerals has proceeded quite far.

At 3350 feet an entirely new rock, as far as macroscopical appearances go, begins gradually to appear. This rock is of the texture of the pinkish diorite so common on the surface, but is almost black in color, with the peculiar luster of augitic rocks. The microscope shows it to be a true augite diorite, precisely the same rock as the surface stone except that its augite is fresh or only slightly altered. The usual amount of free quartz is present, as in all these rocks, and likewise some few flakes of biotite. This phase of the diorite mass appears to be the core of Mt. Davidson.

Proceeding farther in the tunnel, the pinkish rock tends to reappear gradually beyond 4500 feet, and at 4700 feet a peculiar mottled facies shows itself. This has not yet been investigated, but is merely a variety of the diorite. At 4908 feet in, the "west fault," as it will be called, occurs, beyond which appears the "west diabase." The rocks of this section, when properly studied, will complete the work of Hague and Iddings east of the lode, and will serve to bring into greater relief the admirable work of these men.

CONCLUSIONS.

Form of Lode.—The Comstock lode is divisible on structural grounds into two main portions: (1) the Virginia City portion, and (2) the Gold Hill portion. The Silver City fault and lode, or "branch," as now called, is a distinct unit, probably of later age. The grounds for this belief are, as seen, the facts of it being a distinct fault, and that the vein filling is different from that of the Comstock lode proper. The only grounds for a belief in a later age are those of structure; it is well shown that much faulting took place after the first formation of the main lode, and to combine all the facts presented it is necessary to assume a period of faulting not coincident with that which formed the bonanza gashes, but later than the first faulting. In this country of great and long continued faulting such an assumption is not without a good basis.

The Virginia City portion of the lode is bounded on both north and south by a series of east-west faults. Also, to the north, some forking of the lode occurs, with one strong branch bending

to the east in the Sierra Nevada ground. The faults or slips to the south are those approximately in and east of Bullion Ravine. But few of these east-west fractures contain much secondary mineral. The few which do become veins are largely calcite bearing, and probably of different age from the others. Between these two lines of east-west motion is located the Virginia City portion, differing from the other part in having a greater relative movement of the foot and hanging walls. This motion has been so great that an unequal movement of the hanging wall block was produced, the bottom moving farther than the top, with consequent rupture. These ruptures produced the secondary vertical gashes, or veins of rifting. This motion causing rupture, however, was distinctly later in age than the first vein forming movements. Hence, when the secondary openings were formed, they were filled with concentrations from the previous deposits as well as with original supplies from great depths. And there is no good reason for assuming that either the movements or the ore deposition have ceased, but rather all facts tend to confirm the idea that ore is yet being moved from place to place in the greater depths as well as fresh supplies from below being brought up by the hot waters.

In the Gold Hill portion the relative movement of the walls of the lode has been less; there have been no rift veins formed, and the ore bodies are within the lode walls, near the hanging. The same two periods of deposition of vein-filling were present here, the bonanzas occupying later fissures near the hanging wall of the earlier vein. No doubt deposition is still progressing in depth here, though not enough mining work has been done to allow a definite statement in this regard. The one exception to form in this portion of the lode, in the Yellow Jacket mine, was due to the fact that the vein, in its proper plane, did not reach the surface, so that the relative movement of the hanging wall block downward was taken up near the surface by a gash or rift.

Deposition of Ores.—On account of the importance of the subject, a reiterated statement is not out of place regarding the two periods of ore deposition. Had the second of these periods not existed, there would be practically no ore on the Comstock, hence the relations of these two must be of vital concern. The

first period of vein-filling was due to the primary faulting, and low grade materials were placed in the open fissure. The second and later period opened new fissures, rift veins in Virginia City, and openings within the vein in Gold Hill, in which the rich concentrated ores of the bonanzas were deposited. This second period probably continues in the depths, as it would surely do above were the lode still intact from man's hand. The details of this ore deposition have not yet been thoroughly studied out, nor can they be until our knowledge of the physical chemistry of the subject is more complete.

Location of Bonanzas.—The deep ore bodies of Virginia City have been, and will be, found within the hanging wall, in more or less vertical fissures, of which the surface "east vein," the Great Bonanza, and the vein now being worked, are examples. More such bodies should be found by properly-driven cross-cuts and drifts lower down and to the eastward. There is also a large stretch of the lode above the 2150 feet level which has not been thoroughly explored. The probable reason for the peculiar rifting of the hanging wall block is that the cementing of the first fracture by quartz, and the concomitant weakening of the hanging wall by the leaching action of the ground waters, enabled the later stresses to fracture the hanging wall block as it is found. The reason for believing in the existence of still deeper similar rifts filled with ore is that the surface for two miles eastward from the lode shows the hanging wall block to be greatly altered by the action of hot waters, and therefore weakened. The Sutro tunnel section corroborates this, and the mine workings also show the rocks east of the lode not to be solid nor unaltered.

Also, there is considerable concentration of ore taking place from above by the surface, or vadose, waters. These ores will occur on or near the footwalls of the numerous branches of the lode which outcrop on the surface, within a few hundred feet of the outcrops. Such material is low-grade, however, and, in the main, not yet available because of the high cost of mining and milling. A body of future reserves is thus assured. The low-grade of these ores has been proved by numerous assays. Further, the west wall of the lode has never been thoroughly investigated, and such work might prove very profitable.

Structure and Genesis of Mt. Davidson.—Mt. Davidson is a diorite mass bounded on all sides by faults, and has risen relatively to the surrounding country. The Comstock lode occupies the fissure made by the east fault bounding the mass. The west fault now shown in the Hale and Norcross tunnel is not occupied by a vein in the tunnel, because the compressive stresses have been too great. Farther search, both along this fault, and particularly farther west, may easily result in the finding of ore. There are no reasons for assuming the non-existence of ore in the west country, nor elsewhere in the faulted region surrounding Mt. Davidson, especially to the south, where the country is more fractured and broken.

A further word concerning Mt. Davidson may not be amiss, although the subject has not been fully investigated, on account of the time necessary. On the Carson sheet* the mass of Mt. Davidson is seen to be a roughly rectangular mass approximately two by one and one-half miles, with the major axis north and south, bounded on all sides by steep slopes. The eastern slope is noted for the Comstock lode. The surface of this mountain mass is that of an old eroded region, as noted by Becker† (pages 184 *et seq.*), which has been uplifted above the surrounding country. One standing on the summit of Mt. Davidson cannot fail to be struck with the mature character of the topography. This eroded, gently rolling surface exists well preserved in the Sierra Nevada to the west, now broken and displaced by later faulting action. The history of the Sierra and Virginia ranges is identical in the main features. These statements will be proved by a citation of facts in a subsequent paper now in preparation. The results of this conception are obvious and far reaching. The location of the Comstock is well known on the east. On the south are other ore bodies in the American Flat region, but all of the south has not been prospected. One well developed west fault has recently been shown in the Hale and Norcross tunnel, and more will follow. The maximum faulting on the west is farther to the west than the present face of this tunnel. To the

* Carson Topographic Sheet, U. S. G. S.

† G. F. Becker, op. cit.

such several quartz bodies are known to exist on the surface over the broken country, but the details here are not yet known. There is abundant reason for suspecting the existence of ore on other sides of Mt. Davidson than the east.

University of Nevada,
Reno, May, 1905.

NOTE.—At the present date, July 6th, 1905, it can be definitely stated that ore has been discovered in well-formed veins in the Jumbo District, about two miles west of the Comstock Lode, on the west slope of the Davidson Plateau. Also, the Hale and Norcross Tunnel, though not yet far enough west to develop ore bodies, has cut into a large flow of warm water in the favored "west" country.