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CONSOLIDATED VIRGINIA, COMSTOCK.

Notes from Report by Oscar H. Hershey, May 28th, 1934.

Correction(?) to Becker's 1882 mapping. Becker, in his section thru the C&C shaft, shows the lode as an alternation of 3 bands of quartz and 3 bands of mineralized diabase. Hershey thinks the diabase is Mt. Davidson diorite (FW is diorite). FW of lode shows an irregular and discontinuous band of fine-grained replacement quartz.

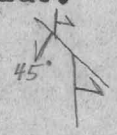
Along the ridge west of the Ophir tank there are two small areas of dark green igneous rock called "intrusive andesite" by Hershey, and supposed to be xenoliths in the diorite. 350' x 100', and 150' x 75', respectively. On W border of smaller xenolith is a short segment of good-looking iron-stained quartz. Another unprospected quartz vein, traceable for 900', lies near the Ophir tank, "back of the lode proper" (probably in the FW), a rather narrow band of qtz. showing ribbon structure. Dips SE 50° near bottom of Ophir ravine; farther SW it may have a reversed dip. It widens to more than 50' where it has intrusive andesite in the NW wall, replacement quartz in the SE(?) Hershey "SW", wall; but where in the diorite alone, it is only 5-10' wide.

Comstock Lode. Western (FW) band. N20E; width varies from 40-250'. A zone of silicified diorite with many seams of rather coarsely crustified quartz. Somewhat porous and iron-stained at the surface. One surface cut was deep enough to cut material showing fine-grained galena and other base sulphides. Dip at the surface seems to be steeply westward, hence Hershey avoids term FW band; but this zone represents the early period of vein action (i.e. mineralization closely resembling that of the main or footwall Comstock lode) found near the footwall of the Comstock lode.

An escarpment due to deep mining in the Con. Virginia and California mines has formed, apparently over a length of 1900', ~~and apparently along this western band.~~ The quartz seen along the escarpment is crushed and yellowish, and resembles that of the second stage of mineralization, that characterized farther south along the lode by calcite-quartz orebodies. Thinks the subsidence that formed the escarpment has occured along the FW of a band of qtz. different from that of the western band described. Evidently the two are close together, for without the escarpment a vein would have been exposed 1800' long and 400' wide. Debris obscures the picture. Apparently a diorite horse between the two bands.

Eastern Band. Seems to be associated with a strong gouge fault, called the "East Clay" of the early miners. This has crushed and dragged the quartz in contact with it. Back of it is a greenish andesite, the diabase of Becker. Fault dips 70W. E Clay flt. in FW of qtz band

Transverse faults. (1) Quartzvein, N45W/45SW 10' qtz., Fe, Mn stained. Light grey gouge band on HW. Comstock lode displaced by extension of this fault up Ophir Ravine, for the replacement quartz band is shifted NW 400' on the NE side of the fault. Lode on the NE side of the fault appears to be much narrower than on SW side.



If Comstock lode dips normally, i.e. E here, displacement is apparently reverse; but if Comstock dips west then normal movement suggested. Upper parts of lode stand steep ~~to~~ Prim. part dip

Vein narrows at fault from 550' width(SW) to 150'(NE). About where this fault projects downward old maps show little exploration. May not have picked up faulted segment in the large Mexican claim; may be large

orebodies here,near surface.

(2).Spanish Ravine fault. N55W;Hershey thinks lode has been shifted NW several hundred feet on the NE side of the fault. Subsiding block mentioned lies between the Ophir Ravine avd Spanish Ravine faults. Bonanza stopesin this block. Spanish Ravine fault in part pre-mineral. East Clay fault looks post-mineral.(The East Clay I think is paralle to these steep-dipping subsidiary membersof the Comstock vein system,since it dips 70W). Hence he thinks East Clay may cut the other faults;and says that if the East Clay reverses its dip at shallow depth, as seems possible,the movement must have been largely horizontal,else the rocks would have been crushed in a broad belt. Thinks east side has moved southward.

Old Upper Workings to 250' level. Considerable bodies of intrusive andesite with the lode,probably xenoliths like those seen on the surface. Varies from dark green,fine-textured to typical intrusive andesite ~~xx xx~~ such as is common on the E side of the lode. More vein matter seems to have been formed in the andesite,but higher values seem to have been found in veins formed in the diorite.

Ore guides:Presence of ZnS,ccpy,py and PbS in the quartz. These occur in fine grains irregularly disseminated through hard quartz or in seams or pockets of pure sulphides to several inches thick. These latter do not assay as high as might be expected;but they must be present to make the vein matter assay more than a dollar ~~xxx xxxx~~ or two. Ccpy since mining oxidized to chalcanthite,pale blue hydrous sulphate. Zone of oxidation was shallow in very hard quartz;at its bottom,some sooty chalcocite and malachite.

Gophering at Con.Va.end of mine;real stopes at Ophir end. On 75' level from S shaft (Con.Va.end) vein is 30' wide,dips 45°W. Ore only as small irregular chimneys. On the Ophir end however the east qtz.vein was largely stoped. Shaft sunk in a filled stope, fill said to run $7.00-8.00 per ton. Crosscut in HW of stope shows 20' grey qtz.with sulphides. May be ore. 157' level.filled stope 400' long,mostly narrow,a paystreak in a vein 35-50' wide. For 150' stope may have averaged 25' wide. 4' roof sample ran $14.75.

Between East vein and next vein to west,horse or belt of nearly barren diorite. To 140' wide. On 75' level from S shaft this horse bounded by PM flt N25W,dip W 65-75.Strong 40'qtz band sliced off obliquely by this flt. This may be E vein faulted NW as much as 100'. Small stopes in this vein; qtz formed in large xeneoliths of intrusive andesite,to 55' wide.Diorite on HW side of vein,another reason to think this vein a segment of the E vein. It dips 45W. Unless movement was horizontal,the PM fault must be a reverse flt.

The barren diorite rib seems to pinch with depth.

Report on Ophir and California Mines by Howard W.Squires,May30th,1934.

Location: N end of Comstock lode,in Va.City.Adjoin.Ophir bounded on N by Mexican claim;675'on lode. California bounded on S by Con.Va claim; 600' on lode.

Lode a series of parallel veins. Old Ophir bonanza,surface to 500' said to have produced $20,000,000. The California produced ~~much~~ a great deal of lower grade ore from the surface,1859-1872.

Ore Blocks: A. California South Orebody. Apparently to 104' level. Massive white qtz, irregular shape, dip (pitch?) to W at 40°, seems to rake down to the N, and widens with depth. 35' wide, 75' long on 75' lev. Smaller above. 123' bottom level. No workings below. Tonnage on basis of 75' ave. length, 25' width, 295' on dip, allowing 100' exyension below 123' lev. 553,125 cu.ft. 25% removed by workings, leaving 414,844 cu.ft. @ 13 cu.ft./T equals 31,972 tons. Value, from 130 samples, ave. $11.69/T. Contained value $373,752.

B, Calif. N Orebody. Massive white qtz. Developed, 207' level and above. Vertical, as wide E-W as N-S. 60' wide and long. 3000 squ.ft., developed vertically 202'. Allow 50' up and 50' down. 606,000 cu.ft. 20% removed, leaving 484,800 cu.ft. or 37,292 tons. Value $5.82/T. Contained value $217,039

C. Ophir orebody. Triangular. 11,230 tons, @ $6.26, $70,299.

D. Ophir. 33,692 @ $7.89, $262,797.

E. Ophir. 19230 tons, @ $6.73, $126,533.

F. Mathews. 21,769 @ $19.43, $422,796.

G. Ophir. 20' wide. 27,138 tons @ $5.01, $135,961.

Total 182,314 T @ $8.28, $1,609,177.

Dump Ores. Gold figured @ $35, Ag @ 64 1/2 c. Dump ore 25,000 tons, first dump. No. 1 Tunnel, 50', 21 samples. Ave. $4.81. No. 2 Tunnel, 60', 24 samples $6.64. 42 samples $ 5.32.

Brewery Dump. 70,000 tons. 17 samples: $4.85; 79 samples: $2.39; 26 samples: $3.80; 52 samples: $3.20; 14 samples: $3.38.

Costs: Most orebodies must be timbered. Square sets.

100 Tons: Mining $3.14; milling $1.42. 300 Tons: Mining $2.00; devel. $0.24; mill $1.25; office $0.15; misc. $0.49. Total $4.14.

Cost of Shovelling from Surface Open Cut. At Arizona Comstock, now delivering 300 tons ore to mill, from open cut. Company does sampling, drilling, blasting, and direct gaspower shovel as to ore and waste or overburden. Contractors furnish shovel (7/8 yard tractor shovel, swing 40'. Also trucks. They shovel and deliver ore to mill for 50 cents/T. Total cost to deliver ore 60 c/T; waste removal adds 20 c/T.

Block H, figured later. 41,539 T @ $8.68, $360,558.

Total now 223,853 T, $1,969,735, ave. $8.80/T. 95% recovery, cost $4.13/T, net profit $4.23/T, or net of $946,898.

DAS GUTACHTEN FERDINAND VON RICHTHOFENS UBER DEN COMSTOCKGANG UND SEINE BEDEUTUNG FUR DIE GEGENWART.

(The Opinion of Ferdinand v. Richthofen on the Comstock Lode and it Present-day Significance).

B. Knochenhauer: Zeits.fur prakt.Geol.,47 Jahrg,Heft 3, Marz 1939,42-53.

Translation in Abstract.

1. Introduction.- The development of the German mining industry especially in the last decade,has been marked by a decided change in emphasis from ore (Erz) mining to that of coal and potash. Once the German ore miner wandered to the ends of the earth and was sought after as a teacher. At present the mining of ore has dropped to 0.6% of the total production of German mines. Because of the Four Year plan, it is now necessary to direct the emphasis once more to the mining of ore.

Eduard Suess called the Comstock the greatest precious metal deposit; von Richthofen made the first scientific study of it,and the later American geologists-Becker, King, J.A. Church etc.,built upon the foundation furnished by v.Richthofen. Unfortunately his report is not available in German, and has never been entirely and correctly published at all. The Sutro Tunnel Co. has suppressed it; stray copies only are found in private hands.

The U.S.G.S. under King later published a monograph: Geology of the Comstock Lode and the Washoe District, Mono.3, 1882,by G.F.Becker; there also appeared the other standard reference work-Comstock Mining and Miners by Eliot Lord,in thesame year.(Can't find any reference to this in "Geologic Lit.N.A".) Becker's monograph contains an abstract of Richthofen's conclusions;in many places the abstract is faithful, but many conclusions are ommitted that appear worth knowing today. One does not realize, from Becker, who the authour of the conclusions is,and he gives neither the beginning nor the end of the Richthofen report. Especially, all the reasons are ommitted that argue the practicality of a deep tunnel. Lord does not even mention v.Richthofen. These omissions may be corrected only by recourse to the original report, together with the two monographs.

The report was delivered to the board of trustees of the Sutro Tunnel Co. on the 22nd November,1865. Sutro, a native of Germany, had by 1860 realized the necessity for a drain tunnel. But it was only in February,1865,that he had the necessary funds spromised. In Paril 1866 the plan was formulated as a cooperative enterprise of the larger companies. Since Richthofen's report had already been delivered it is a fair assumption that it formed the basis of this entreprise. In spite of this, the actual financing was slow because powerful opponents to the scheme arose;the most powerful was the Bank of California,which offered mining companies cheap money forpumping;on this most of the companies took back their pledges. The impatient hope to make big money from the bonanzas as soon as possible affected the companies more vitally than did any anxiety for the long-term future;the latter was what R. had had in mind.

Sutro was undiscouraged;nevertheless many years passed before financing reachedthe stage where work could begin. In Sept.1871 a compromise satisfactory to both sides was reached,and then only after the

industry had suffered greatly from flooding of the mines. And after all, the financing had to be by European capital. The tunnel was finished in 1878,much too late to be of maximum service;for by that time most stopes had passed beneath the tunnel level,and had been mined in manners that would have been unnecessary had the tunnel been there before. The whole story was one of trouble and vituperation,and this probably explains why R. would not remain longer in America despite Whitney's pleas,and why he never wrote about the Comstock again. This is all the more regrettable because after all these years and the great advances made since it was written,the report must still be considered a notable work. The observations and conclusions laid down in it are not to be discarded today. On the contray, they should prevail over the many other attempts at explanation of the genesis of ore deposits that have sprung up since,and that have lead to incorrect generalizations The only things to be changed are the views on the petrographic character of many Comstock rocks. This translation of the report into German should be all the more welcome because concerning R's activities in America (1862-1868)there is nothing to be found,either in German literature or in the papers left behind on his death. The work below is based on his original report;ommitted are merely certain details on the mine workings;however,many parts of the report are abbreviated.

The Comstock lode lies on the east flank of the Sierra Nevada... The Washoe district is a plateau of about 2000 m. elevation. Locally, deeply incised canyons have cut down to 1500 m;the Virginia (Mt.Davidson range) rises several hundred meters above the average elevation of the plateau.(Mt.Davidson-2400 m).Virginia City itself, and the outcrop of the lode lie at about 2000 m. elev. The accompanying plan and sections are reduced from Becker.

In R's time the greatest depth reached hardly exceeded 200 m.;the Sutro tunnel was to tap the lode at a depth exceeding 500 m. Opinion was divided as to wheter the lode would descend to this depth. Richthofen decided it would,with the qualification that especially rich bonanzas would become rarer with increasing depth. As 900 m. was passed at the end of 1880,minable ore was still being found in satisfactory quantity. That nevertheless the work was mostly stopped at this depth was due to the unexpected influx of hot water,unknown in R's day.... Later the genesis of the hot springs was investigated. Becker found that they were hottest at the lode,decreasing in heat with distance from it. R showed, 50 years before his time, that the source of the lode minerals was in the depth of the earth; Becker leaned toward the lateral secretion theory.

2. The Comstock Lode and the Question of its Extension in Depth.-

General Geology (Abridged).

The Washoe district represents a transition phase between the Sierra Nevada and the Great Basin. It has in common with both the many Tertiary and post-Tertiary eruptives;these help make up its structure. Mt.Davidson is composed of diorite;north and south of it lie metamorphics the youngest of which is Triassic. In part overlying the metamorphic beds is quartz-porphyry. These rocks make up the higher portions of the range. Of the Tertiary rocksonly two have relation to the lode;they are eruptive and belong to the latest Tertiary and post-Tertiary periods of extrusion. The older is the Propyllite. It is the main country rock of the lode;such rock incases many,perhaps most of the mightiest silver ore bodies of the world:the Carpathians,Mexico and probably also Bolivia. The wall rock in Virginia City,Gold Hill and American City is propyllite.

Of the other eruptives that followed the extrusion of prpyllite, only the trachyte has any connection with the lode, inasmuch as it probably caused its formation, and besides forms an important part of the regional structure. The manner of its formation was that it rose in long fissures in viscous or liquid condition, and at high temperature. Trachyte tuff occurs as well; the massive trachyte however outcrops in jagged horsts in a semicircle around Washoe Lake. Silver veins are not found in the trachyte itself. After this extrusion period basalt extrusionstook place in neighboring parts of the Great Basin; but these have little siginificance for Washoe. The volcanic activity gradually died out, the last phase being hot springs.

General Structure of the Lode.

The Comstock lode trends N15°E along the east front of the Virginia range. Its course shows a relation to the shape of the mountain front, for it shares all its irregularities: concave bends (to the west) coicide with ravines; convex (to west) curves mark the ridges. The greatest convex (to west) bowing is at the unbroken foot of Mt. Davidson itself. These irregularities are significant because they influence ore localization (? look like flat-dipping vein in rough topography). The lode is proven for 5800 m. along the strike, but probably extends 7000 m.

Single ore shoots are 150 m. or more deep; shafts over 200 m. deep. In general the workings give a clear picture of the vein in its upper horizons and form the basis for sound conclusions as to persistance in depth.

From 150-180 m. in depth the vein fills a fissure 30-40 m. wide, but narrows locally so that the walls touch. The dip is 40-60°E. Above the approximate depth of 150 m. the footwall retains this dip; but starting at this depth the hangingwall turns steeply upwards and even turns over to give a west dip of 45°. The vein widens therefore toward the surface like a funnel. However, this wide part contains great horses of wall rock only slightly moved from their original positions. Some of these are nearly 300 m. long, 15-30 m. wide. The spaces between these horses are filled with vein matter, the quantity of which in relation to that of the horses decreases going up. The total width of this upper zone exceeds 150 m.

The wall rocks of the lode vary. On the east they consist of propyllite in different varieties, in places very fine-grained, almost aphanitic, in places breccia with sharply angular fragments. On the west diorite occurs, forming the scarps of Mts. Davidson and Butler. North of Mt. Davidson both hanginwall and footwall are prpyllite.

The outcrop of the lode consists of scattered rows of quartz masses sticking up above the surface and forming a zone locally 180 m. wide; this zone is often discontinuous. The western (footwall) part consists of quartz mostly crystalline glassy, and usually white or light colored. Encased in the quartz are frequent angular fragments of wall rock-often crystallization centers. The eastern part, on the other hand, is different in appearance: parts of the wall rocks often occur together with clayey and ore-bearing particles that are finely divided in the quartz and distinguish the latter clearly from that of the western portion of the outcrop. (?: In den ostlichen Ausbissen kommen oft Teile des Nebengesteins zusammen mit tonigen und erzhaltigen Massen vor, die fein im Quarz verteilt sind und sich deutlich von denen der westlichen Ausbisse unterscheiden). A porous texture of the quartz, due to the weathering out of fine particles of ore, and accompanied by the brown or red color of limonite points to ore beneath. The occurrence

of native gold or silver in little pores and in larger cavities indicates an ore body. The chloride and simple sulphide of silver occur in the eastern portion of the outcrop. All these surface phenomena persist to varying depths.

The vein mass consists,apart from the many wall rock fragments, which near the surface make up about 5/6 of the whole,mainly of clay, clayey masses, quartz and sulhides. Where the horses consist wholly or mainly of propylite they wdge out laterally and downwards (sliver-like) those of diorite end more abruptly and are more equant in shape, although also elongated along the vein strike. The quartz is often thinkly filled with such sharply angular fragments. Where propylite occurs on both walls and the fragmentsin the vein are also propylite,the vein takes on a breccia-like appearance.

Clay and Clayey Masses.

Few great veins are so rich in such masses as the Comstock. Clay ledges 3-6 m. thick extend along the east and west walls;they reach 15-20 m. in thickness where the walls approach each other. Other clay "beds" separate the horses from the quartz, or cut through them. Besides these,masses of clay occur in the vein itself ,and in places make up a large proportion of the fissure filling. Most horses grade to clay in their under portions and continue in depth as well as along the strike as clay "beds". Without the lode clay masses are abundant in the east (hangingwall) wall,but seldom if at all in the west or footwall.

Quartz.

The differences mentioned above in the quartz of the outcrop continue with depth,but are harder to see on account of the general white color of the vein. But the finely-divded particles of wall rock in the quartz are more plentiful in the east or hangingwall than in the west or footwall,in depth as well as at the surface, and always the most plentiful where the quartz carriesore. The quartzis seldom massive,so that explosives are seldom required in mining;in general the quartzis so finely divided as to resemble pulverized sugar (Becker: common table salt).

Ore.

The main ore minerals are stephanite,polybasite (Sprodglaserz), native silver and very silver-rich galena. Less plentiful are ruby silver(does not say whether pyrargyrite,proustite or both),hornsilver and polybasite (all dictionaries,Dana etc, call Sprodglaserz polybasite). Also native gold, pyrite,blende,chalcopyrite,cerussite and "Buntbleierz", the last two being very rare.

The lode is very poor in other minerals. The ore minerals are seldom crystalline and museum specimens are rare. Quartz is practically the sole gangue;calcite and other carbonates are rare. Of the sulphates only gypsum occurs.

The distribution of the ore is different in the northern and southerns parts of the lode. In the north the ore bodies are extended lenses 5-16 m. wide,the major axes of which stand nearly vertically.Locally these are called chimneys. In the south the ore bodies are tabular, longer but narrower than the chimneys. Both types are found in the east or hangingwall portion, sometimes in the middle portion, but never in the west or footwall part.

The richest and largest bodies occur under strong outcrops. In the north the lode as now worked is extremely poor under ravines;in the south ore persists at such crossings. The richest parts are south of each crossing. All the chimneys of the northern segment are found where the walls, after nearly coming together, quickly separate ,and vein matter comes in again. All the main concentrations of ore are where the fissure gave the quartzthe greatest room in which to deposit;on the other hand,ore bodies are with few exceptions lacking where the vein contains an extraordinary proportion of horses.

The grade in general has decreased with depth. In the early years $600 ore was no rarity. Today (1865) the average grade does not exceed $32.00. ...The gold ratio decreased in the early years,but with increased depth the proportion has returned to its original amount.

The Comstock is a True Fissure Vein.

Characteristics of True Fissure Veins. 1. They cut through different rocks without change. 2. They descend to unknown depths.3. They show dynamic activity plainly. 4. They generally occur in connection with volcanic extrusions;where this is not clear on the surface,disturbances of the strata and metamorphic effects hint at it. 5. They are mainly filled from below,and essentially by chemical processes.

All the above criteria are especially evident in the Comstock lode. That the Comstock is a true fissure vein is clear also from negative considerations,for instance, by its lack of analogy with other known kinds of veins as (1):Gash,i.e. shrinkage fissures,formed through loss of moisture of drop in temperature. They are restricted to one sole formation,and are filled from above or from the sides. (2) Segregated Veins. These never fill preexisting fissures;their metal content was furnished by gradual extraction of the constituent parts from the surrounding wall rock. They never show clay selvage or horses,and show no signs of dynamic activity.(3.)Contact veins. The Comstock was formerly considered such. (Diorite footwall,propylite hangingwall). But when it was learned that it traversed propylite aline in its north end, this notion was abandoned. Its being is dependent on the contact between diorite and propylite in the south end only because this contact was a plane of less resistance than the massive rock on either side. 4. Intrusive veins are completely homogeneous and formed by forcible entry of ascending solutions in a preexisting fissure. They never have gouges.

The Comstock corresponds to none of the above classes;on the contrary,all positive and negative criteria show that it has all the characteristics of true fissure veins to an extraordinary degree. It is not always easy to tell the true nature of a vein;this is not the case with the Comstock.

Genesis of the Comstock Lode.

Each vein is a law unto itself,having its own characteristics and differing from all others. A comparison of all the major silver veins would show great differences in country rock, length and breadth,gangue and ore, distribution of the valuable metals,vein structure and its relation to the wall rocks. This being the case, it follows that veins differ in their genesis.Infiltration from above or from the sides,thermal action and other processes have all been sited as sole causes for the formation of ore-bearing veins. But work in all districts shows that all these processes worked more or less together and that differences result from the dominance of one or the other process,and through the

inflaamee of the wall rocks.

The Comstock lode was filled neither from above or from the sides, for none of the surrounding rocks could have furnished such great masses of gangue and ore. Even had this happened, the vein would show a banded structure, by no means the case. The east (HW) side might on account of its extreme decomposition be regarded as a lateral infiltration. But the decomposition was effected by ascending solutions which have left clear traces behind them and which could have removed no material lateraly.

Thermal springs, considered by many authorities as the most likely agency in the formation of every true vein, do not explain the genesis of the Comstock lode. With such springs silica tends to deposit around the fissure opening. While erosion is likely to remove such deposits, they could not have been present at the Comstock because the surface has been modified only slightly since the formation of the lode. Besides, the alteration of the country to the east within a radius of more than 6 km. cannot be explained by thermal springs.

To discover the true impelling force that moved such enormous masses from a deep-seated source into the Comstock fissure we must trace the origin of fissures and then observe which processes during the formation of fissures of equal size appear to apply.

Origin of Fissures.

The Comstock fissure must necessarily be younger than the propylite. The only process that could have produced such a mighty effect was the eruption of the trachyte, which accompanies the lode 3 km. away to the east. Continually increasing stress below the massive crust of surface rocks must finally have fractured them and thereby released the xxxxxx forces that caused the stress.

Filling of Fissures.

With active volcanoes the formation of a fissure is followed by a mighty giving off of vapor, the so-called solfataric activity. This passes through several stages with time. In the first the vapor is accompanied by gaseous fluorine and chlorine compounds, in the second by SO_2, while the third stage is usually marked by the outpouring of carbonic acid and of hydrocarbons. This stage however is passed the solfataric.

In the elemnts that characteryize the solfatara in the two first stages, i.e. fluorine, chlorine and sulphur, we see all the conditions fulfilled to account for the formation of the Comstock lode. Steam, which ascended with the gases of fluorine + silicon (? "Fluorsilizium") ~~effected~~ formed, through drop in temperature and pressure in the upper regions, precisely known chemical processes, silica + silicic-fluorine-acid (Kieselfluorwasserstoff saure), the first as a solid, the second as a volatile gas that has effected great decomposirion in the wall rock. Chloride of silicon forms with hydrogen silica or HCl. Fluorine and chlorine are the most powerful known volatizers and enter into compounds with nearly all known substances. Beside silica, the metals have a great affinity for them. All of them that are found in the Comstock lode could have ascended in gaseous form in connection with one or the other of these volatalizers. They must then have been deposited in the upper parts as oxide or chloride or as native metals. So the fissure was gradually filled from top to bottom with all the elements that we see today in chemical compounds.

A fissure is usually not unchanged after its first opening;later processes widen it or close it. New channels are opened if the old ones have been filled. When after such a formation of an opening inside the vein mass which had filled the old fissure an influx of gas rich in vapors followed,then conditions existed for the formation of major ore bodies. At the time of the fissure filling,the ascending gases worked on the wall rock,the nature of which was entirely changed. Joints were formed (Risse) and filled with the same substances as the vein fissure. Since the vein dips east and the forces were directed toward the surface,only the hangingwall was thus affected. Branch fissures from the main fissure would probably pierce the hangingwall,and it is to be reasonably expected that with depth one would discover such branches,probably ore-bearing.

Alteration of the Vein.

Altering activity began very early. SO2 and sulphuric acid soon became dominant and introduced the second solfataric stage. The main process in this alteration was a purely chemical one. The silica separated out from its fluorine and chlorine compounds as a gelatinous mass having an entirely different appearance from that of the crystalline quartzof the vein. Metallic oxides and chlorides were changed to the corresponding sulphides, and the absence of antimony (sic:Abwesenheit) should be Anwesenheit,presence) caused the formation of sulphantimonides the most important of which is stephanite. Through such processes the whole vein mass was gradually changedto its present-day appearance.

It is notable that there is hardly a single chemical agent,outside of fluorine and chlorine ,that causes deposition of non-metallic substances in exact or nearly exact inverse proportion to those that appear in silver veins(?:...dass es kaum ein einziges chemisches Agens gibt,ausgenommen Fluor und Chlor,das nichtmetallische Substanzen in genau oder nahezu genau umgekehrten Mengenverhaltnis zu dem ablagert,indem sie in Silbergangen vorkommen). Iron and manganese are not only more common in rocks,but are also easier dissolved and carried away by acids than are silver and gold. The proportion of these former to the latter metals would have been less,if theirremoval from their original source had been effected by agents other than fluorine and chlorine. Only these two would have combined with these metals to begin with,which are rarest in rocks and most plentiful in silver veins. And they are probably the only elements that originally deposited in greater proportion,in spite of their later strong alteration,wherin watter played a very important role.

Dynamic Activity in the Vein.

The repeated widening and local narrowing suffered by the fissure after it first opened,was followed by the loosening of pieces of the hanging. Small pieces,which fell in during the formation of vein mass,caused the breccia-like structure,while larger ones slid down until they encountered support. Other dynamic processes that still continue,manifest themselves in the formation of clay selvages on the walls and within the vein. They show a shearing movement of the vein mass along the walls,and of one part of the vein mass against another part. Few veins show such a notable plasticity of the vein mass as does the Comstock.

Additional indications of solfataric action are visible in the neighborhood, The belt of hills which appears at the foot of the above-mentioned trachyte mass shows these especially. The belt consists of propylite,hardly recognizable as such because completely decomposed

and changed to a rock mainly clay of red and yellow color;the feldspar and hornblende phenocrysts may however still be recognized. Numerous joints,from which the decompisition has proceeded give evidence for the veryical ascent of the altering solutions. Who has seen solfataras will be surprized at the similarity between their chemical reactions and those shown east of the Comstock lode.

The continuation of the lode in depth hasoccupied the minds of all in Washoe,and is of the utmost imprtance regarding the future... It was shown above that the Comstock lode is a true fissure vein which by solfataric action formed as a consequence of the trachyte eruption. Since the active forces came from below,they must have found a clear channel,in order to have made possible a connection between the processes at depth with the place of deposition above. There is no need to doubt the continuation of the vein in depth.

As the manner of this continuation,we may only speculate,no matter how numerous and well-founded may be the supporting facts. The dip will probably not change much,for the hangingwall is very regular indicating coninuity of dip;also,the HW solfatric activity in the east indicates that the lode underlies this region at depth. Concerning the average width no precise prediction may be made. The walls of every true fissure are warped surfaces. Through the downward movement of one against the other protuberances of one wall come opposed to those on the other;also concavities may become opposed. This is the reason why every great fissure shows repeated openings and narrowings. It is to be expected that the Comstock lode will present the same picture in depth as at present explored;its average width will probably remain the same as at present exposed in the deepest levels. The formation of great horses is,on account of the nature of their origin,charactertistic more of the upper than of the lower levels,since the breaking down of the hanging would occur where the vein was weakest. Since among the agents,fluorine and chlorine have most strongly effected the wall rocks,the quantity of small fragments will very probably increase with depth,causing an increase in the breccia structure and the barren parts,which will then mainly lie above those places where the vein is crushed,as may be seen today.

The wall rock will not change much. The structure of the region shows that the south part of the Mt. Davidson range already existed when the extrusion of the propylite built the mountain massive on the east, and that its steep scarp continues down below the belt of round hills. The fissure probably follows the ~~boundary of~~ contact between the older Mt. Davidson rocks and the younger propylite massive,for this was a plane of least resistance,compared with the massive rocks on either side of the contact. Only there, where the old slope swerves from its direction and where Tertiary rocks may have filled the deporessions,may the fissure have broken through these Tertiary rocks. But the ravines in the old range which were earlier just as today and which ~~dip~~ extend down under the propylite would have some influence,because the vein passes across them in notably concave curves. Presumably this will continue to be the case at depth, even though not always unfavorable for ore. When a change in rock does occur at depth,the propylitie will probably dissappear on the west(east? and diorite predominate more and more.

~~Ore distribution and localization is in~~ No branch of mining so has had so many vicissitudes ~~erratic~~ as ~~in the~~ silver mines. The history of the Mexican mines as described by Humboldt and Ward gives may examples. Mines abandoned as worthless after great production were reopened after long periods and became again productive;this repeated etc. The causes for the shutdowns

were either impoverishment of grade or rising costs of pumping or legal or political difficulties. In the first two cases the success of reopening lay in either improvement of the ore or the technique.

The Valenciana mine on the Veta Madre of Guanajuato encountered in 1760 a portion of the vein that had been worked in the 16th century, and abandoned as unprofitable for nearly 200 years. In 1768 a bonanza was encountered at about 80 meters depth which gave annually ~~ix~~ $1,500,000. Even from 1788 to 1810 the yearly output exceeded $1,380,000. A deeper shaft, nearly 600 meters deep was sunk; but the ore extended only to a depth of 400 m. and then turned to waste. In 1810 the mine closed down. 15 years later the Anglo-Mexican Co. unwatered it, but the ore brought no profit. The mine now belongs to the United Mexican Co. and has produced very well for a number of years by milling larger quantities of lower grade ore.

The Veta Grande of Zacatecas, which produced from 1548 to 1832 about $666.000,000 lies like the Comstock lode in propylite and has a similar structure, i.e. it dips about 42° and is shattered toward the surface. Its wodth is somewhat less than that of the Comstock, in general less than 12 m. At one place only does it reach 25 m. It contains clayey masses and contains great fragmentsof wall rock. In the upper levels the ore occurred in vertical chimneys, extensive and very rich, but at depth, where the ore was more widely distributed, it was poorer...

Ij both cases the ore became poorer in depth, but more regularly distributed, and its great quantity has given good profits. Any change in the nature of the ore is not established: it remains pure silver ore through all levels.

Many other mines show the same thing, especially in central Mexico. It is different in the northen states. The silver deposits there are fanous for their quantity of native silver and rich ores. The empoverishment was due the the predominance of lead over silver.

The same thing holds for the silver mines of the Carpathians, all of which oocur in propylite and resemble the Comstock in many ways. The gangue of the Grossbrube in Felsöbaya is almost its counterpart. This mine, like that of Schemnits, is supposed to have had great production, although the management was poor. The Romans mined extensive ore veins. At depth however the ores were much too poor, so that under the crude methods they gave poor results. But the impoverishment was caused mainly by the predominance of lead and copper ~~axar~~ at depth; while true silver ores ~~seldom~~ became rarer. At the same time their distribution through the whole vein became more regular, although they formed therin always smaller streaks and bolsas.

Other mines show equal silver content at all depths. Those near Freiberg, where bonanzas occur at various levels, have with depth oftener improved than fallen off. Those near Kongsberg in Norway have produced from time to time bonanzas down to the deepest (600 m) levels, and have lately produced more than ever. Those of Catorce and ~~xx~~ some other Mexican mines show no falling off in depth, and have excellent ore at depths of 600 and 700 m.

If now one compares the Comstock with the best-known other mining districts, one sees that it differs from a certain class of narrower veins, which, such as those of Freiberg, Kongsberg, Chanarcillo in Chile, Pasco, Peru, Catorce and Austria in Nevada(Austin?) fill a quantity of smallfissures, which either parallel one another or cross, and which at

depth retain the appearance and grade they show near the surface. The Comstock on the contray shows all the characteristics of another class of silver veins marked by their size and simplicity:mother lodes,in general surrounded by samaller veins of less importance. To this class belong the veins of Schemnitz and Felsobanya in Hungary,the Veta Madre of Guanajuato and the Veta Grande of Zacatecas,while the veins of Potosi in Bolivia and of Real del Monte belong more to the first class. These great mother lodes resemble one another in many ways: All fill fissures of extraordinary length and width,seem to have a very recent origin and also have close relation to volcanics,which accompany them. Although the rules of ore distribution are more or less different for each, all have been very rich in metal,to whatever depth they may have been explored,and it seems that at every horizon nearly the same quantity of silver occurred. (Guanajuato is an exception), One may perhaps conclude from this that they will do the same to the greatest depths. But there is a difference in depth in the enrichment of silver:the bonanza ore is usually found in well-defined bodies in the upper levels,while in depth,although similar bodies are to be find,even larger ones, they are usually lower in grade. This explains the larger yield of the upper levels of most mines.

To return to the Comstock and see what conclusions may be drawn as to its future.

It must first be realized that the ore mined on all levels ~~is true~~ has remained pure silver ore ~~than~~ such as occurred at the surface. Lead,copper,iron and zinc ores have never been important in the Comstock,and these metals keep about the same relative importance with depth.An increase in lead would be a poor sign for the future,for this would show that lead was more and more taking the place of silver;the lower limits of ore were fast being reached. But as things stand to day,no such impoverishment is to be expected,although some drop in grade.

Conclusions.

From the facts of the Comstock lode itself, and from comparison with other districts,the following conclusions are justified:

1. The downward extension of ore on the Comstock lode must be considered, disregarding local discontinuities,exactly as certain as the downward extension of the vein itself.

2. It is certain that the ore will retain its character of true silver ore to unknown depth.

3. Extensive ore bodies as rich as the surface bonanzas will probably not be found in depth.

4. Increase in size of ore bodies with depth is probable.

5. At depth, a considerable part ofthe ores will not differ in grade from that now mined in the deepest levels;but an increasing quantity of lower grade ore will appear. This follows from the similarity of all deposits outside of their surface bonanzas and the homogeneity that nearly all show through their whole extent.

6. The ore will at different levels change from certain parts of the vein to others, as it has done heretofore. Greater regularity of distribution may nevertheless be expected below the shattered portions, full of fragments,where the vein will probably take on a more even and regular appearance. A few mines, hitherto unproductive,have therefore

good prospectsin depth. But in general it is more likely that the footwall will remain barren, as before,while the whole space between this and the hangingwall is to be considered the future source of ore. As noted above,it is probable that more than one branch vein will be found at depth, of clay and quartz, rising in the hangingwall perpendicular to the main vein. Many of these will carry ore. Search should be made for such ore bodies in all the eastern mines. The experience in the upper levels indicates that the ore of such bodies will be richer than the average on the main vein.

7. A suddenly barren zone atvdepth,such as that described on the Veta Madre of Gto,at 400 m. depth appears very unlikely for the Comstock. The reason for this is geologic:it is well known that the wall rocks exerts a great influence on the quantity and nature of certain ores in veins,and that a true vein entering a different formation often becomes barren. In the Veta Madre the drop in grade at the 400 m. level took place where the vein entered a diffrent formation,which continued from there on down. (Not true-E.W.) Such a change is not to be expected for the Comstock vein because the regional structure shows that the present wall rocks continue to unknown depths.

Note.- The report ends with a list of the advantages to be secured from driving the Sutro Tunnel.

DISSERTATION

A CONTRIBUTION TO THE GEOLOGY OF THE COMSTOCK LODE

R. R. Coats

Ph D Exam. U.C. Aug 30 '38.

The number of formations exposed in this area is small. All the rocks seen at the surface are Tertiary or Quaternary in age, although older rocks have been found in some of the mine workings. The oldest formation shown on the map is a series of hornblende and augite andesite flows and breccias, with a thickness of five to six thousand feet. Included in these is a member, several hundred feet thick, composed largely of water-laid rhyolitic tuffs and breccias. Intrusions, probably nearly contemporaneous with the explosions which produced these breccias, emplaced sills of albitophyre in the andesite. This series of rocks was folded and tilted westward, and invaded by a diorite stock and by dikes of andesite porphyry. At about the same time fractures trending east-west and north-north-west were developed. After intrusions further movement took place on these fracture systems, and on the north-north-easterly trending faults of the Comstock system. Veins were developed along these faults; movement continued during and after the mineralization. After the mineralization, a long period of erosion ensued, during which the region was reduced to one of low relief. During the Pliocene, further faulting took place, concomitantly with the eruption of a series of andesite flows and breccias, and the intrusion of several plug domes. Most of the later lavas were removed by erosion, which stripped them from the surface of low relief on which they were laid down. Probably toward the end of the Pliocene further faulting, with a throw of 1500 feet or more, took place on the Davidson fault, which coincides with the footwall of the Comstock Lode for most of its length. Since the faulting, erosion has trenched both the footwall and hanging-wall blocks of the Lode.

The intrusion of the Davidson diorite resulted in baking and contact metamorphism of the surrounding rocks, Subsequently, hydrothermal activity produced a widespread propylitic alteration. Hydrothermal solutions rising

along the vein fractures produced a moderately widespread pyritization and, close to the vein, an intense sericitization and silicification. Subsequen to the erosion, supergene agencies produced minor kaolinization and alunitization of the rocks which had been pyritized.

Microscopic study of the ore specimens showed that deposition of the veins occurred over an extended period, repeated fault movements brecciating the veins and forming openings in which the later, economically more important minerals could be deposited. The earlier deposited minerals suffered replacement, re-solution, and redeposition. Supergene enrichment has not been important.

DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

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BONANZA ORES OF THE COMSTOCK LODE VIRGINIA CITY, NEVADA

BY

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BONANZA ORES OF THE COMSTOCK LODE, VIRGINIA CITY, NEVADA.

By Edson S. Bastin.

INTRODUCTION.

At certain periods in the long and diversified history of mining on the Comstock lode the engineering problems of handling the treacherous floods of hot mine waters and the problems involved in the struggles for financial control of the mines have seemed to outweigh all others in influencing the progress of deep mining. Yet more fundamental than these or other problems has been the geologic problem of persistence of ores in depth. If the rich silver ores were wholly or largely deposited from solutions ascending from deep-seated sources this fact should encourage deep exploration. If the bonanzas owed their richness to the action of waters of surface origin on ores that originally were comparatively poor in gold and silver, then little encouragement to deep mining is offered. With the steady progress in the metallurgical treatment of low-grade gold and silver ores the probable persistence in depth of ores of this class also assumes practical importance. No serious observer expects a revival of the golden (and silver) age of Comstock mining, for fracturing on a tremendous scale created the channels that made ore deposition possible, and this fracturing was more extensive near the surface than at great depths. Nevertheless, the "roots" of an ore deposit of such magnitude are of no mean proportions, and the confidence of the Comstock operators in the existence of large deep-lying bodies of workable ore has been demonstrated by the drainage in recent years of a large part of the lode to and below the 2,900-foot level. It is the purpose of this paper, by reporting the first detailed microscopic studies on Comstock ores, to offer additional encouragement to deep exploration and not merely to illuminate the already brilliant achievements of the past.

In spite of the very detailed studies that have been made of Comstock geology, very little concrete and tangible evidence has been presented concerning the variations in tenor or composition of the ores in depth, and little basis has been available for weighing the relative importance of primary processes versus downward enrichment in the formation of the richer ores. Yet because of the recog-

nized potency of downward enrichment in many silver deposits a tacit belief in its importance at the Comstock seems to have become current among many geologists and mining engineers.

The early work of King[1] and Becker[2] was done before the development of the concept of enrichment of ores through the agency of descending surface waters. Later observers have made only brief examinations under conditions most trying because of the high mine temperatures. Finally, the ores themselves being as a rule fine grained, it has been impossible to determine the mutual relations of their different minerals by observation with the unaided eye.

The writer visited the Comstock in 1913 for the purpose of collecting representative ore specimens from various depths on the lode for study, after polishing, through the metallographic reflecting microscope. His visit was only partly successful, for it was possible to procure in Virginia City only a few specimens from depths near the surface and from the older shallow bonanzas. Many specimens from the deeper workings were obtained, however, and through the courtesy of Dr. George P. Merrill, of the United States National Museum, these were supplemented by the original collections of Dr. Becker containing many ore specimens collected near the surface and at moderate depths. The writer is greatly indebted to Mr. Thomas McCormick, superintendent of the C. & C. mine, for a number of specimens of the richer ores, and to Mr. W. G. Hellier, superintendent of the Union Consolidated mine, for other specimens and for the careful collection of a sample of the deep mine waters for analysis. The publication of the results has been delayed by professional work in South America and later by work incident to the war.

EARLIER INVESTIGATIONS.

Baron Von Richthofen, who made the first noteworthy geologic study of the Comstock, in 1865, plainly considered that the ores had been deposited by ascending hot solutions, in part gaseous and in part liquid, and concludes with the words: "As it has been shown that the vein was filled from a deep-seated source, it is certain that it is continuous in depth."[3]

Clarence King[4] also considered that the bulk of the ores had been deposited by hot ascending solutions, which he believed to be connected with volcanic activity, and concluded that geologic indications were at least not unfavorable to the finding of valuable ore bodies at considerable depths.

[1] King, Clarence, The Comstock lode, in Hague, J. D., Mining industry: U. S. Geol. Explor. 40th Par. Rept., vol. 3, pp. 11–96, 1870.

[2] Becker, G. F., Geology of the Comstock lode and the Washoe district: U. S. Geol. Survey Mon. 3, 1882.

[3] Becker, G. F., op. cit., p. 21.

[4] Op. cit., p. 21.

as the descending water at Tonopah[23] shown diagrammatically in figure 13, but in the Tonopah water free acid is much less abundant, as might be expected from the prevalence of carbonates as gangue minerals. The sample collected by Reid also belongs to the same general class as a water collected by Chase Palmer and the writer from the Genesee mine, at Red Mountain, Colo. The analysis of this water has not yet been published, but the quality of the water is shown diagrammatically in figure 13. This water was dripping from limonite stalactites in the roof of workings in ore body No. 3, about 600 feet below the surface. It is proportionately much richer in metals than the Comstock or Tonopah waters, but it carries no free acid.

In the above comparisons of Comstock waters the factor of concentration has been purposely eliminated. It is important to note, however, that the cool descending water is more than 200 times as concentrated a solution as the hot ascending waters.

CONCLUSIONS.

The application of detailed methods of microscopic study to a considerable number of specimens from the Comstock lode obtained at depths ranging from a few hundred feet to 2,900 feet shows with a reasonable degree of conclusiveness that in ores from depths greater than 500 feet, including the bulk of the bonanza ores of the lode, the silver is essentially all in primary minerals. Descending solutions of surface origin produced an important increase in the silver content of certain ores within 500 feet or less of the surface, yet even in such situations a part of the silver content is in primary minerals, and some rich ores from slight depths showed no secondary silver minerals.

Gold, so far as observed, is primary in all the ores.

Although the occurrence in the deep portions of the lode of ore bodies comparable in size and richness to the great bonanzas of the past is not to be expected, yet the primary origin of some of the rich ores offers encouragement for deep development.

The hot ascending mine waters of the Comstock lode are essentially sodium and calcium sulphate solutions. Similar waters are characteristic of certain sedimentary formations, but the association of these waters with igneous rocks and the fact that they carry measurable quantities of the precious metals suggest that they may be related to the solutions that deposited the primary ores. The hot waters of the Comstock resemble somewhat the deep hot mine waters at Tonopah but are poorer in carbonates.

[23] For occurrence and analysis see Bastin, E. S., and Laney, F. B., op. cit., pp. 29, 44.

fig. 8.) At Tonopah carbonates are abundant as gangue minerals and as alteration products in the wall rocks, and it is therefore natural that the weak acid radicles (CO_3 and HCO_3) should be more abundant in the waters than at the Comstock. The Tonopah water resembles that of the Comstock, however, in the abundance of alkali radicles and the paucity of metal radicles. The thermal spring waters of Ouray resemble those of the Comstock in the great dominance of strong acid radicles (mainly SO_4), but the alkali radicles are less abundant.

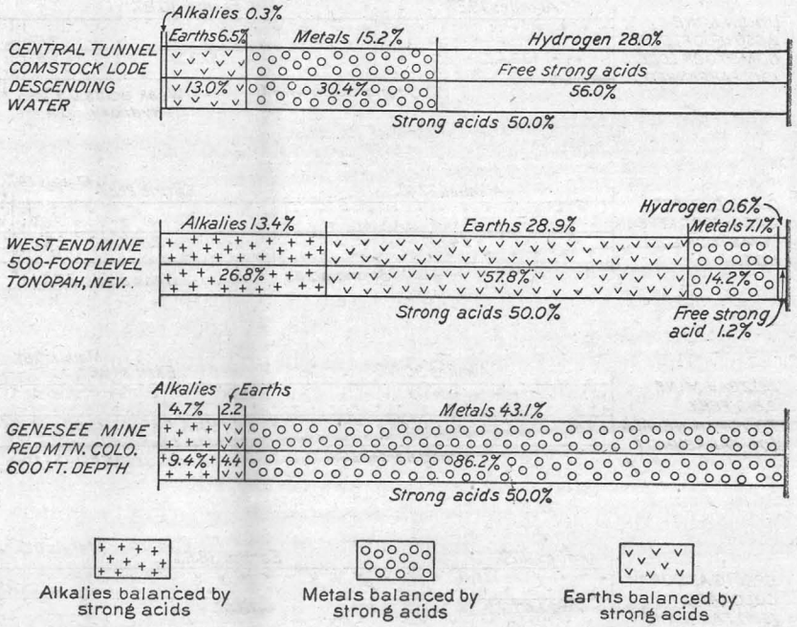

FIGURE 13.—Composition diagrams of cool descending mine waters from Comstock lode and Tonopah, Nev., and from Red Mountain, Colo.

At the time of visit in 1915 there were no favorable opportunities for collecting mine waters from the upper levels in the Comstock lode, but about 1904 John A. Reid [22] collected a sample of cold water descending through the lode from a point about 100 feet below the surface in the Central tunnel. This analysis is shown in the table on page 60 and in figure 13. Its chemical characters are in marked contrast to those of the hot deep waters, especially in its poverty in alkalies and the abundance of metals and of free acids.

The quantity of free acid, mostly H_2SO_4, present is remarkable but becomes understandable when it is recalled that carbonates that would neutralize free acid are exceedingly rare both in the ores and in the altered wall rocks. This water belongs to the same general class

[22] Op. cit., p. 192.

Both King and Von Richthofen deemed it unlikely that the "magnificent expansion of bonanzas" that characterized the upper levels would be repeated below.

Becker,[5] like his predecessors, believed that the ores were deposited by ascending thermal hot solutions but thought that the metal content of these solutions had been leached from the altered rocks adjacent to the lode, a conception which has now been generally abandoned by students of ore genesis for deposits of this type.

Thus none of the earlier students of Comstock geology attached any great importance to descending solutions in the formation of the ores beyond recognizing the familiar change wrought by oxidation in the shallow zone, 300 to 500 feet deep, between the surface and the original ground-water level.

The only important later contribution to the geology of the Comstock is that by Reid in 1905.[6] Although partly devoted to the structure of the lode this paper shows that the hot ascending Comstock waters carry both gold and silver and are very probably now depositing metals in the deeper parts of the lode. In the upper parts of the lode acid waters descending through it are depositing certain minerals, and an assay of the waters revealed both gold and silver. Apparently Reid does not believe that descending solutions have produced any of the bonanza ores, for he says:[7]

> 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 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.*

Particularly indicative of the deposition of rich silver ores by ascending solutions is the occurrence of such ores at depths of 1,800 to 2,250 feet in a blind vein in the hanging wall of the main lode, a vein which does not appear at the surface even as a barren fracture.[8]

Before passing to the microscopic characters of the ores, the mineral composition as recorded by King should be noted. He says that the main ore mass of the bonanzas is composed of quartz (several generations), pyrite, sphalerite, galena, chalcopyrite, argentite, polybasite, stephanite, and calcite. Polybasite and stephanite occur in all the bonanzas, but rarely in well-defined crystals. Gypsum occurring locally and the oxidation products of the upper parts of the veins complete the list.

[5] Op. cit., pp. 285–287.

[6] Reid, J. A., The structure and genesis of the Comstock lode: California Univ. Pub., vol. 4, pp. 177–199, 1905.

[7] Idem, p. 197. (Italics are mine.—E. S. B.)

[8] Idem, p. 183.

SUMMARY OF MICROSCOPIC ORE CHARACTERS.

The salient results of the microscopic studies are recorded here for the benefit of those who are not concerned with the full details.

The ores of the Comstock lode are characteristically fine grained, the grains of the metallic minerals being commonly less than 1 millimeter in diameter and only rarely attaining diameters of 5 to 10 millimeters. Because of this fineness microscopic study is necessary in order to determine fully the mutual relations of the minerals. The texture is usually granular; banding is rare and where present is of the somewhat ill-defined type developed in ores formed by replacement. Well-defined crustification developed by deposition on the walls of fissures or irregular open spaces is very rare.

The ores studied came from depths ranging from a few hundred to 2,900 feet.

The abundant minerals in nearly all the ore specimens are quartz, sphalerite, galena, chalcopyrite, and pyrite. Calcite may occur sparsely or abundantly. These minerals are intercrystallized in a fashion indicating that all were deposited essentially contemporaneously during a single period of mineralization. No one of this group characteristically replaces or fills fractures in any of the others or shows any other evidences of having been deposited at a different period.[9] Inclusions of each of these minerals were noted in essentially all the others.

The textural relations typical of these common ore minerals are shown in figures 5 to 8. As will be noted from these figures, the galena and chalcopyrite, as well as argentite, gold, and polybasite, commonly occupy a matrix-like or interstitial position between the crystals of quartz and sphalerite. This position does not indicate that the interstitial minerals belong to a younger period of mineralization, for inclusions of quartz and sphalerite may be noted in all of them; it shows, however, that quartz and sphalerite crystallized most abundantly early in the mineralization period.

The common ore minerals, quartz, calcite, and the base-metal sulphides listed above, are present in all the ores, from those close to the surface to those at depths of 2,900 feet, and throughout this range in depth show similar mutual relationships. Because this mineral association ranges unchanged through this noteworthy vertical interval in apparently complete independence of any processes originating at the surface and because hot mineral-bearing waters are even now rising along the lode this group of minerals is interpreted as a primary deposit from hot mineral-bearing waters rising from great depths toward the surface. The waters at present ascending

[9] An exception is to be noted in occasional white quartz or calcite traversing sulphide-rich ore and clearly younger.

Solutions may have rotted rock as they rose in rifts + so formed imperious walls.

The two analyses of Comstock deep hot waters are in general very similar, and the noteworthy features they show are these:

1. The abundance of alkalies (Na and K), as compared with cool descending waters.

2. The abundance of strong acid radicles (mainly SO_4), as compared with weak acid radicles (CO_3). The small proportion of carbonate radicles present accords with the scarcity of carbonates as gangue minerals in the ores and in the wall rocks altered ("propylitized") by solutions that were presumably somewhat similar to those analyzed.

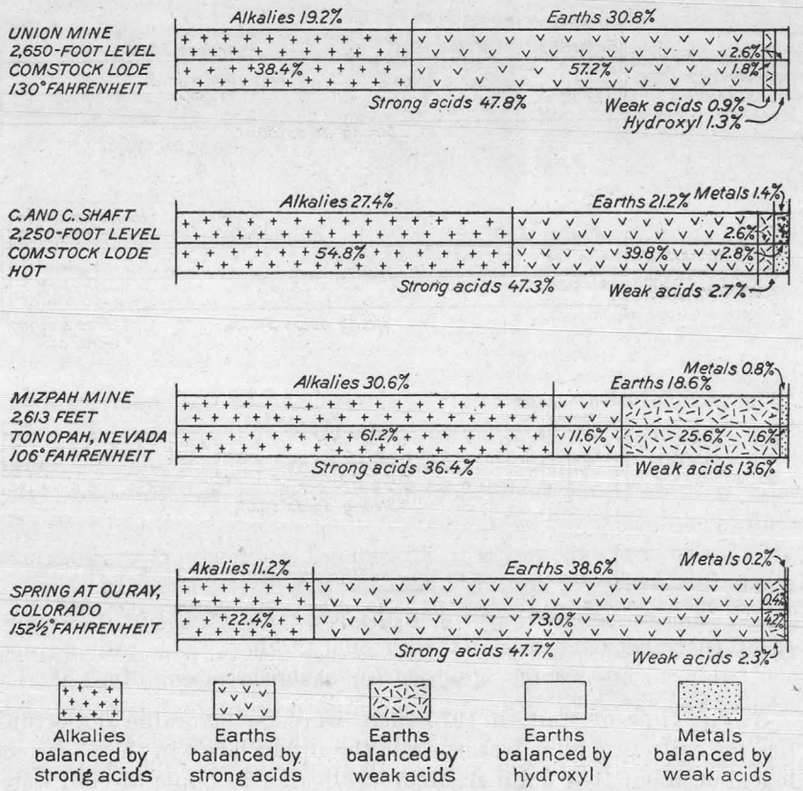

FIGURE 12.—Composition diagrams of hot ascending waters from Comstock lode and Tonopah, Nev., and from Ouray, Colo.

3. The small amounts of heavy metal radicles present, as contrasted, for example, with the descending mine waters shown in figure 13.

The Comstock deep waters belong to the same general type as the deep hot mine waters of Tonopah, Nev., and the thermal springs at Ouray, Colo., and may profitably be compared with them. (See

Analyses of mine waters from Comstock lode—Continued.

Descending water, Central tunnel.

[Analyst, Prof. N. E. Wilson, University of Nevada.]

As reported (grams per liter).		As recalculated.				
		Radicle.	Parts per million.	Reacting value.		
				By weight.	Per cent.	
Na_2O	0.7209	Na	534.9	23.3	0.3	50.0
CaO	1.7400	Ca	1,243.4	62.0	6.5	
MgO	10.8108	Mg	6,520.8	536.0		
Al_2O_3	18.2140	Al	9,659.6	1,069.3	15.2	
Fe_2O_3	7.1786	F_2	5,020.8	269.6		
Mn_3O_4	1.2500	Mn	900.3	32.8		
CuO	0.1850	Cu	147.8	4.7		
		H (by difference).			28.0	
SO_3	70.1154	SO_4	218,645.0	4,547.8	50.0	
H_2SO_4	125.0804					
Cl	0.1276	Cl	127.6	3.6		
SiO_2	.6160	SiO_2	616.0			
	236.0387		243,416.2	6,549.1	100.0	

	Per cent.
Alkalies+strong acids	0.6
Earths+strong acids	13.0
Metals+strong acids	30.4
Free strong acids	56.0
	100.0

The perusal of a water analysis as reported by the analyst affords slight indication of the chemical properties of the water. In order to visualize these properties and to facilitate comparison with other water it is necessary to recalculate the analyses and to express the results graphically. The method of study adopted is that developed by Palmer [20] and expounded in its geologic applications by Rogers.[21] Its details need not be repeated here, but briefly it consists in expressing the several radicles present in the water in terms not of weight but of their capacity to react with one another. The radicles are then balanced against one another (or assumed to combine) in the order of their general chemical combining power, alkalies being first balanced against strong acids, remaining alkalies against weak acids, and remaining strong acids against alkali earths, etc. The balancing thus accomplished may readily be expressed graphically, as shown in figures 12 and 13, and by eliminating the factor of concentration and considering only the components other than water in the solutions different solutions may be instructively compared.

In figures 12 and 13 the reacting values of the positive radicles are entered above each diagram and those of the negative radicles are entered below; each group adds to 50 per cent, and combined they make 100 per cent.

[20] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

[21] Rogers, G. S., The interpretation of water analyses by the geologist: Econ. Geology, vol. 12, pp. 56–88, 1917.

along the lode carry small amounts of the precious metals and though not analyzed for base metals probably carry these as well. The conclusion that the bulk of the ore minerals were deposited by ascending solutions is in harmony with the conclusions reached by King, Von Richthofen, and Becker.

Inasmuch as the Comstock ores are worked as a source of gold and silver, chief interest attaches to the mode of occurrence of minerals carrying these metals. If it can be shown that the precious-metal minerals are wholly or in large part of the same age as the commoner ore minerals they also are to be interpreted as a deposit from ascending solutions. If this is true, then there would seem to be no reason why bodies of rich ore should not be found at great depths.

In the great majority of the specimens studied, coming from depths ranging from 2,500 feet to a few hundred feet of the surface and including samples of some of the richest bonanza ores, the only precious-metal minerals present in notable amounts are argentite and gold. The gold is invariably very pale yellow and therefore is probably highly argentiferous. All the gold in these ores and nearly all the argentite occur in exactly the same textural relation to sphalerite and quartz that is characteristic of galena and chalcopyrite—that is, argentite, gold, galena, and chalcopyrite occur side by side as a matrix between areas of quartz and sphalerite. Neither gold nor the larger areas of argentite show any evidence of having replaced other minerals or filled fractures in them. These relations, characteristically shown in figures 5, 6, and 7, are interpreted as showing that all the gold and the larger areas of argentite are primary and were deposited contemporaneously with galena and chalcopyrite. As shown on a later page, minor amounts of argentite are secondary. Many argentite areas are of the same order of size as galena areas. Areas of gold 1 millimeter across were noted. In one specimen numerous minute round or oval inclusions of argentite were noted irregularly distributed through both galena and sphalerite. These show no evidence of having been formed by replacement, neither their form nor their distribution being related to cleavage directions of the galena. In another specimen occasional small inclusions of argentite were noted in gold and in chalcopyrite. All these inclusions are believed to be primary.

In a few specimens, as illustrated in figure 8, polybasite occurs in relations similar to those characteristic of argentite and gold and is interpreted as a primary mineral. It is rare, compared with argentite. In other specimens tarnishing of the galena with hydrogen peroxide reveals scattered inclusions of rounded outline that were too small for identification but are very possibly a silver mineral.

In most of the specimens studied secondary minerals, to be discussed later, were either absent or present only in amounts too small

to have any great influence on the tenor of the ore. The conclusion is therefore reached that essentially all the gold of the Comstock ores is primary and that the silver content of some of the richest bonanza ores is also in primary minerals—argentite and rarely polybasite.

If the gold and silver of the Comstock ores are in the main in primary minerals, as the observations recorded above seem to show, are there any evidences that the precious-metal value has been anywhere increased through the enriching action of descending solutions of surface origin? This query must be answered in the affirmative. Minerals deposited by descending solutions may occur in two ways—as replacements of primary minerals or as fillings of cracks or cavities in the primary ores. Replacement in the sense here used means the dissolving of an older mineral and the immediate deposition in its place of another mineral without the intervening formation of open spaces.

Replacement on a scale capable of materially influencing the tenor of the ores was noted only in ores obtained within a few hundred feet of the surface. This is considered valid evidence that such replacement was accomplished by descending solutions. The replacement was of several kinds.

Replacement of chalcopyrite by covellite and by chalcocite was noted in ore from the 300-foot level of the Hale & Norcross mine, and replacement of chalcopyrite by covellite was noted in ore from the 350-foot level of the Andes mine. The covellite or chalcocite formed replacement borders around the chalcopyrite or penetrated it as replacement veinlets. No such replacement was observed in ores from greater depths.

Replacement of argentite by native silver was noted in ore from the Belcher bonanza obtained probably from depths of less than 350 feet. This replacement is shown in figures 9 and 10. In small pores in this ore minute wires and "teeth" of silver were also noted on argentite. In ore from a depth of probably less than 425 feet in the Gould & Curry mine silver also replaces argentite. In both these specimens the argentite is primary, for it occurs in the same textural relationships as galena.

In the specimen from the Belcher mine noted above argentite which is probably primary is peripherally replaced by polybasite in the fashion shown in figure 11. No such replacement was noted in deeper ores.

In ore from the 350-foot level of the Andes mine galena was replaced peripherally and along fractures by lead sulphate (anglesite).

In ore collected from the Hale & Norcross mine soon after mining operations were begun nearly every area of galena has been replaced peripherally by argentite or by a galena-like mineral, probably a lead-silver sulphide, as described in more detail on pages 55–56. These

the United States Geological Survey, and the analysis is recorded in the following table and diagrammatically in figure 12.

Analyses of mine waters from Comstock lode.

Hot water from 2,650-foot level, Union Consolidated mine.

[Temperature 130° F. Analyst, Chase Palmer, U. S. Geol. Survey.]

Radicle.	Parts per million.	Reacting value.		Adjusted reacting value (per cent).	
		By weight.	Per cent.		
Na	145.0	6.3075	18.7	19.2	50.0
K	8.4	.2150	.6		
Ca	204.0	10.1796	30.2	30.8	
Mg	4.0	.3288	1.0		
Mn and Fe	None.				
SO_4	752.0	15.6416	46.3	47.8	50.0
Cl	12.0	.3384	1.0		
CO_3	9.3	.3097	.9	.9	
HCO_3	None.				
OH	7.5	.4410	1.3	1.3	
SiO_2	61.0				
	1,203.2	.....	100.0		100.0

	Per cent.
Alkalies+strong acids	38.4
Earths+strong acids	57.2
Earths+weak acids	1.8
Earths+hydroxyl	2.6
	100.0

Hot water from 2,250-foot level, C. & C. shaft.

[Analyst, Prof. N. E. Wilson, University of Nevada.]

As reported (grams per liter).		As recalculated.				
		Radicle.	Parts per million.	Reacting value.		
				By weight.	Per cent.	
Na_2O	0.1765	Na	131.0	5.70	27.4	50.0
K_2O	.0643	K	53.4	1.37		
CaO	.1404	Ca	100.3	5.00	21.2	
MgO	.0097	Mg	5.9	.48		
Al_2O_3	.0025	Al	1.3	.14	1.4	
Fe_2O_3	.0091	Fe	6.4	.23		
SO_3	.3957	SO_4	542.6	11.29	47.3	50.0
Cl	.0190	Cl	19.0	.54		
CO_2	.0150	CO_3	20.5	.68	2.7	
SiO_2	.1334	SiO_2	133.4			
	.9656		1,013.8	.....		100.0

	Per cent.
Alkalies+strong acids	54.8
Earths+strong acids	39.8
Earths+weak acids	2.6
Metals+weak acids	2.8
	100.0

NOTE.—Residue from evaporation of 10 liters assayed silver, 2.92 milligrams per ton of solution; gold, 0.298 milligrams per ton of solution.

Trouble with mine waters was experienced even near the surface, for the water-tight clay seams so common along lines of faulting within the lode impounded the shallow waters in numerous separate reservoirs. Reaching any particular level in mining gave no assurance that all the region above that level had been drained.[16] Thus at a depth of 313 feet below the surface in the Ophir mine great quantities of water were let loose when a clay seam was penetrated and flooded the mine to a depth of about 21 feet. Similar incidents are recorded as occurring in other mines. From the data afforded by such occurrences and from the depth of oxidation as recorded by King it appears that the ground-water level stood originally at depths below the surface ranging from slightly less than 300 feet to about 500 feet.

According to King[17] the waters encountered above the 700-foot level ranged in temperature between 70° and 75° F., this being also the temperature of the rocky material of the lode.

On the 1,040-foot level of the Crown Point mine the waters, apparently ascending, had a temperature of 102° F. At depths of 2,000 feet the temperatures of the rock and of the mine waters were originally 120° to 130° F.[18] In 1877 the Savage shaft encountered not far below the 2,000-foot station a flow of water with a temperature of 157° F. In 1880 to 1882 water at a depth of 3,080 feet from a drill hole at the bottom of the Yellow Jacket shaft had a temperature of 170° F.[19] Becker says that on the lower levels the waters, when first tapped by the drill, were frequently under pressures equivalent to a head of several hundred feet.

With continued operations in the deeper levels the mine waters have, as might be expected, become cooler than when first encountered, and the sample collected in 1915 from the 2,650-foot level of the Union Consolidated mine had a temperature of 130° F. Water from the Mexican-Ophir winze on the 2,700-foot level was observed by the writer in 1915 to have a temperature of 149° F.; tested at the point of issuance it was neutral in reaction toward phenolphthalein.

The chemical qualities of the deep waters of the lode have been determined by two trustworthy analyses, which will next be considered.

At the writer's request and in conformity with his detailed suggestions, Mr. W. G. Hellier, superintendent of the Union Consolidated mine in 1915, kindly collected a sample of water from the 2,650-foot level of the mine. This sample was analyzed by Chase Palmer, of

[16] King, Clarence, op. cit., p. 50.
[17] Op. cit., p. 86.
[18] Symmes, Whitman, Decline and revival of Comstock mining: Min. and Sci. Press, vol. 97, p. 496, 1908.
[19] Becker, G. F., op. cit., p. 230.

replacement deposits are conspicuously shown when the galena is tarnished brown by hydrogen peroxide. Argentite that is probably primary is also present in this specimen, but it is probable that 50 per cent or more of the silver content is in secondary minerals. Tarnishing with hydrogen peroxide reveals occasional replacement of galena by other minerals, probably silver minerals, in ores from depths as great as 1,950 feet, but these replacement minerals form exceedingly narrow bands and are not sufficiently large or numerous to affect the tenor of the ore materially.

Enrichment on a scale sufficient to exert any notable influence on the tenor of the ore was therefore noted only in ores obtained less than 500 feet below the surface, and some ores from these slight depths showed no enrichment phenomena.

MICROSCOPIC DETAILS.

ORES FROM DEPTHS OF 1,000 TO 2,500 FEET.

1. Bonanza ore, main lode, C. & C. mine; depth, 1,650 feet. This ore is typical of much of the ore from moderate depths in the lode and will be described before some of the ores from lesser depths, in which the relations are similar but are less clearly exhibited. The ore consists in the main of a fine-grained granular aggregate of the following minerals, named in approximate order of abundance: Quartz, chalcopyrite, sphalerite, galena, argentite, pyrite, and light-colored gold. The argentite and gold are not recognizable to the unaided eye, but the microscope shows that they are fairly abundant. The relation of the argentite to the other ore minerals is shown in figure 5, from which it will be seen that argentite bears identically the same relation to quartz and sphalerite that galena does, and the two are interpreted as of the same age and as primary (hypogene). There are no evidences of replacement of galena by argentite along fractures or cleavages or along contacts with other minerals. Figure 6, drawn from the same specimen, shows light-colored gold in similar relations to quartz and sphalerite to those shown by argentite and galena.

2. Bonanza ore, Hale & Norcross mine, 1,100-foot level; collection of G. F. Becker. This is a heavy sulphide ore, carrying in approximate order of abundance chalcopyrite, quartz, galena, sphalerite, calcite, pyrite, argentite, and pale-yellow gold, all of which are primary, their characteristic relations being the same as observed in ores from the C. & C. mine illustrated in figures 5 to 7. Gold is present in unusual abundance, and some gold areas are 1 millimeter across. Argentite not only forms areas comparable with the galena in size and relations but occurs also in the form of occasional small inclusions in chalcopyrite and in gold.

3. Bonanza ore, Belcher mine, depth between 800 and 1,200 feet; collections of G. F. Becker. Highly quartzose ore ranging in color from white where free from sulphides to gray where there is an abundance of small sulphide grains. The ore is exceptionally rich in calcite, which occupies interstices between quartz crystals. Through the quartz and calcite the usual suite of base-metal sulphides as well as argentite and gold are scattered as isolated grains or small aggregates. The textural relations of argentite and gold are identical with those of the base-metal sulphides, and all the minerals

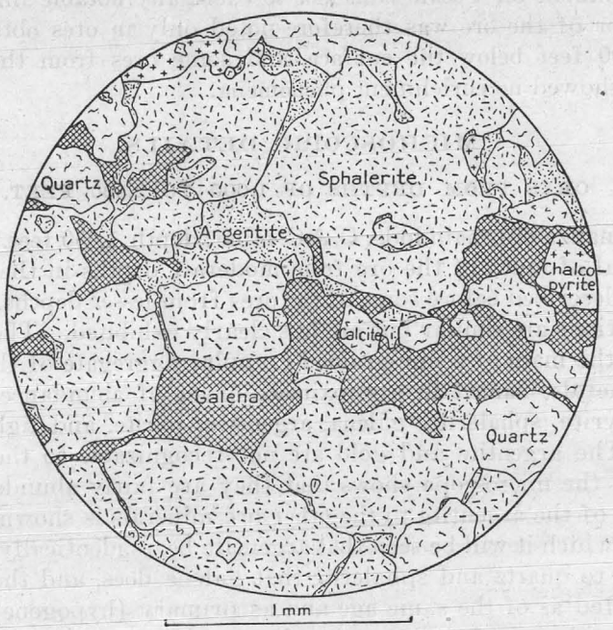

FIGURE 5.—Argentite occupying a similar interstitial position to galena with respect to quartz and sphalerite, in bonanza ore from 1,650-foot level of C. & C. mine, Comstock lode, Nev. All are believed to belong to the same period of mineralization and to be primary (hypogene). Camera lucida drawing from same specimen as figure 6.

appear to belong to a single period of primary mineralization. No replacement phenomena are shown.

4. Fairly rich ore, Alta mine, 200 feet south of Benton line, depth 1,950 feet; collections of G. F. Becker. This ore carries galena in unusually coarse crystals as much as 1 centimeter across in a matrix of much finer grained sulphides. A slightly later $\frac{1}{8}$-inch veinlet of white calcite traverses the quartz-sulphide ore. Ore from which this sample was taken assayed 55 ounces of silver and 0.27 ounce of gold to the ton. The microscope shows in approximate order of abundance quartz, pyrite, galena, sphalerite, and chalcopyrite. Argentite or other silver minerals were not noted in grains comparable in size

5. North bonanza and Flowery mine, 600-foot level; Becker collections. This ore is relatively coarse, showing chalcopyrite areas 5 to 10 millimeters across. It shows the usual base-metal sulphides in a white quartz gangue. No argentite or gold was noted. On tarnishing the galena with hydrogen peroxide very narrow replacement bands, probably of a silver mineral, became visible about the peripheries of some galena areas and between galena crystals. Such replacement bands are a minor feature and can represent only a slight enrichment in silver.

6. Andes mine, north drift on 350-foot level; Becker collections. This specimen carries in approximate order of abundance quartz, sphalerite, chalcopyrite, and galena as primary ore minerals. Secondary covellite forms replacement rims around chalcopyrite and also traverses the chalcopyrite as replacement veinlets. Galena is replaced peripherally and traversed by replacement veinlets of a mineral which in reflected light is slightly darker gray than the associated sphalerite but which when scratched is found to yield a white nonmetallic powder. This mineral, whose hardness is about the same as that of galena, was identified chemically from the hand specimen as anglesite ($PbSO_4$). In its replacement of galena it locally follows with remarkable regularity the cleavage directions of the galena.

7. Gould & Curry mine; Becker collections. This specimen was marked as collected in 1863. The maximum depth attained up to that time did not exceed 425 feet. The ore is fine grained and rich in sulphides. The microscope shows, in approximate order of abundance, quartz, chalcopyrite, sphalerite, galena, and pyrite, with small amounts of argentite and gold.

The argentite and gold are primary, their relations to the other minerals being similar to those shown in figures 5 to 7. Tarnishing the galena with hydrogen peroxide reveals no replacement by other minerals. In spite of its shallow source the precious-metal content of this ore appears to be wholly primary.

MINE WATERS OF THE COMSTOCK LODE.

The mine waters of the Comstock lode have always been of more than usual practical as well as scientific interest, for they have constituted one of the chief obstacles to mining operations. The water pumped from the lode in one year, 1880, about 7,000,000 tons, equaled in weight the total quantity of ore mined from the lode up to that year, and between 1886 and 1898, because of the large influx of water, deep mining was virtually abandoned. In 1898, through a consolidation of operations and the installation of more modern pumps, the contest with the waters was finally won and mining on the deep levels resumed.

the galena brown with hydrogen peroxide, which makes visible also a relation not seen before tarnishing, namely, the invariable presence between argentite and tarnished galena of an untarnished band identical with galena in color and possessing the same perfect cubical cleavage, as shown by the occurrence in it of triangular pits identical with those that characterize galena. The band between galena and argentite evidently represents an intermediate product in the replacement of galena by argentite. The same phenomenon was recognized by the writer in the silver ores of Tonopah,[14] and the conclusion then reached may here be quoted:

> The nature of the intermediate replacement product revealed by the microscope between galena and argentite still remains in doubt; it may be a solid solution of galena and argentite or a double sulphide of lead and silver. Nissen and Hoyt[15] from a study of a series of melts of galena and silver sulphide conclude that "the limit of solid solution at atmospheric temperatures is below 0.2 per cent Ag_2S." The apparent homogeneity of the transition mineral and the extreme sharpness of the boundaries between it and both galena and argentite seem to favor its interpretation as a double sulphide of lead and silver.

The replacement borders of argentite and the unknown mineral occur along nearly all contacts between galena and quartz or calcite but almost nowhere between galena and sphalerite or chalcopyrite. This means apparently that the contacts between galena and metallic minerals were less permeable to the replacing solutions than the contacts between galena and nonmetallic minerals.

It is clear that in this specimen a very considerable part of the silver content, probably over 50 per cent, is in secondary argentite and perhaps lead-silver sulphide developed by the replacement of galena. As replacement on this scale is observed only in the shallow ores of the lode it is reasonable to conclude that it is an effect of descending solutions—that is, of downward enrichment.

4. Low-grade ore, Hale & Norcross mine, 300-foot level; Becker collections. Highly quartzose ore, nearly white where free from sulphides but dark gray where crowded with microscopic grains of sulphides. Parts of the hand specimens are stained brown with limonite. The primary ore minerals, named in the approximate order of abundance, are quartz, sphalerite, chalcopyrite, pyrite, and galena. Some isolated and relatively large areas of argentite in quartz lie adjacent to areas of unaltered chalcopyrite and appear to be primary. The secondary minerals are chalcocite and covellite replacing a few small areas of chalcopyrite peripherally or extending into them as replacement veinlets.

[14] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, pp. 21–23, fig. 12, 1918.

[15] Nissen, A. E., and Hoyt, S. L., On the occurrence of silver in argentiferous galena ores: Econ. Geology, vol. 10, p. 179, 1915.

with the base-metal sulphides, but when the galena was tarnished with hydrogen peroxide numerous rounded inclusions of the order of 0.01 millimeter in diameter became visible in the galena. These are too small for certain identification but are "peppered" very abundantly through some of the galena crystals and are probably a silver-bearing mineral. The only secondary minerals present are extremely narrow replacement bands, probably of polybasite, between galena crystals, but these are too few and too narrow to affect the silver tenor of the ore materially. They appear only upon tarnishing the galena with hydrogen peroxide.

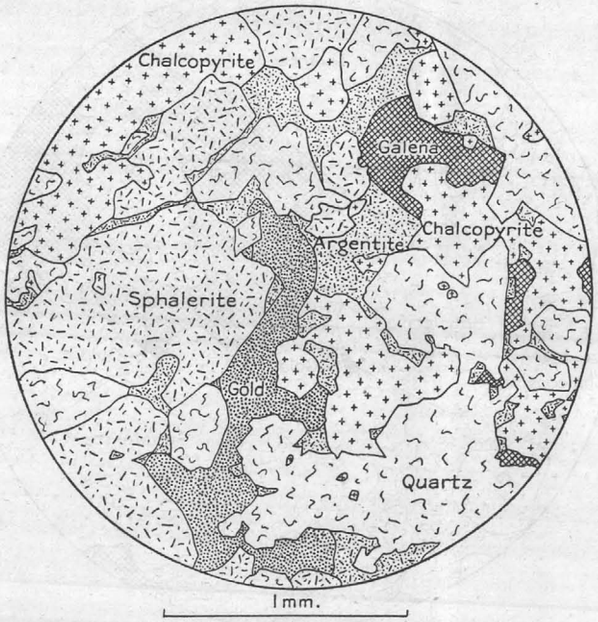

FIGURE 6.—Primary argentite and gold (electrum?) in bonanza ore from 1,650-foot level of C. & C. mine, Comstock lode. Camera lucida drawing from same specimen as figure 5.

5. Bonanza ore, East vein, C. & C. mine, depth 2,000 to 2,050 feet. This specimen was a fragment of a large piece in the collections of Mr. T. F. McCormick. The large piece showed fine-grained ore rich in sulphides traversed by a veinlet consisting mainly of gray quartz with which a few flat hexagonal crystals of polybasite or stephanite were intercrystallized. No clearly secondary minerals were recognized in the large specimen. The microscopic appearance of the portions richest in metallic minerals is shown in figure 7, from which it will be seen that, as in the specimens previously described, argentite, gold, and galena all bear identical textural relations to quartz and sphalerite. This figure shows the somewhat rounded outlines

characteristic of much of the sphalerite, in contrast to the crystalline outlines usually assumed by the quartz. Such rounded outlines are not interpreted in this case as indicative of resorption of sphalerite prior to the deposition of galena, argentite, and gold but as expressive merely of some difference in the forces of crystallization of sphalerite and quartz by virtue of which the quartz more readily develops crystal faces. In parts of this same specimen, however, the sphalerite develops crystal faces. Rounded outlines in sphalerite are common in the somewhat similar ores of Tonopah.[10] The fine-grained

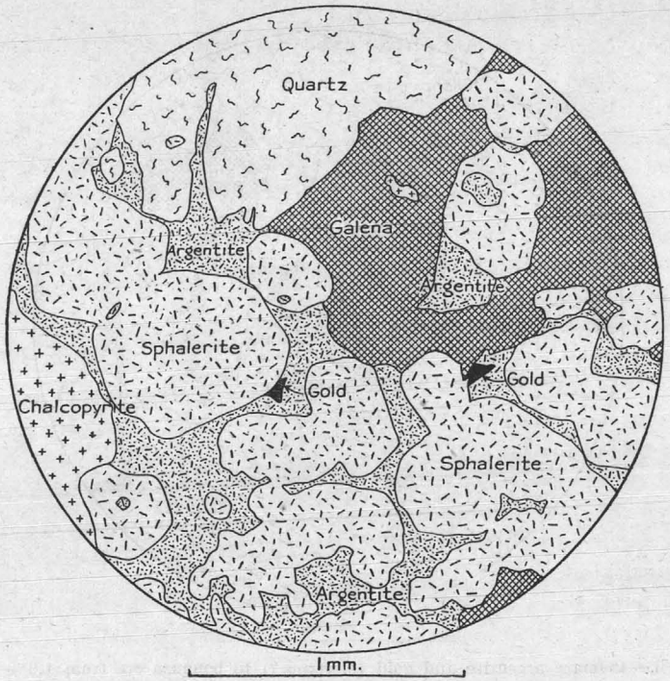

FIGURE 7.—Bonanza ore from C. & C. mine, Comstock lode, East vein, between 2,000 and 2,050 foot levels, carrying abundant primary argentite associated with galena, sphalerite, chalcopyrite, quartz, and gold. Camera lucida drawing.

sulphide-rich portions of this ore from which figure 7 was sketched are traversed by coarser, highly quartzose portions, which appear to represent the latest phase of the mineralization though belonging to the same general period. On and between the coarse quartz occur argentite, polybasite, and some galena in relatively large crystals.

6. Bonanza ore, C. & C. mine, East vein, depth 2,200 feet. This ore shows gradual transitions from fine-grained ore rich in sulphides to coarse-grained ore rich in white quartz and carrying sulphides

[10] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, fig. 10, p. 22, 1918.

In many parts of the specimen the primary argentite has been replaced partly or wholly by native silver, the silver masses forming minute replacement veinlets or larger and more irregular masses in the argentite. Where best developed the replacement by silver has involved no change in volume, and no pores are visible, even under high powers of the microscope. No mineral other than argentite has been replaced by the silver. Tarnishing the galena by hydrogen peroxide reveals no replacement of galena by other minerals.

3. Rich ore, Hale & Norcross mine; Becker collections. The depth from which this specimen came was not recorded, but it was marked as collected in 1860. This date may be in error, for according to King[13] operations at this mine were begun in 1861 or 1862. At any

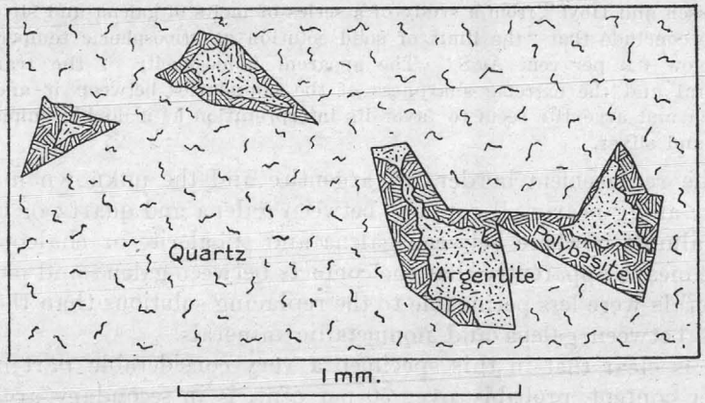

FIGURE 11.—Polybasite peripherally replacing primary argentite in shallow ore from the Belcher bonanza, Comstock lode. The polybasite is believed to be a deposit from descending enriching solutions. Camera lucida drawing.

rate the specimen was probably collected early in the history of the mine and from slight depth.

The ore is fairly rich in sulphides in grains mostly under 1 millimeter in diameter. The primary minerals, named in the approximate order of abundance, are quartz, sphalerite, chalcopyrite, galena, calcite, and argentite. Some of the argentite occurs in relations similar to those shown in figures 5 to 7—that is, in areas comparable in size to the galena areas and bearing similar textural relations to the other minerals. In view of the presence in this specimen of argentite that has replaced galena, as described below, the primary nature of the larger argentite areas can not be demonstrated but is regarded as probable.

Nearly every area of galena shows peripheral replacement by argentite. This relation is brought out more clearly by tarnishing

[13] Op. cit., p. 174.

cate that most of the silver was developed by the replacement of argentite. A hand lens shows, however, that some of the silver in the larger pores assumes the form of wires or teeth. As native silver is found only in ores from shallow depths in the Comstock and is usually in ore that is porous or oxidized or both, it is believed to be a secondary mineral deposited by descending solutions.

In the coarser parts of the specimen some argentite areas show a periphery of polybasite, as illustrated in figure 11. This relationship indicates that the polybasite was developed by the replacement of argentite, spreading inward from contacts between argentite and quartz. Such occurrences were not noted in the deeper ores and are believed to be due to downward enrichment.

FIGURE 10.—Detail, under higher magnification, of the exceedingly irregular replacement boundary between native silver and argentite in the specimen from which figure 9 was drawn.

2. Gould & Curry mine; Becker collection. The original position of this specimen in depth is not given, but it was marked as collected in 1866. Up to 1864 the deepest working was a tunnel cutting the ore body at a depth of 425 feet. In 1864 the sinking of the deep shaft was begun, but prior to the date of King's report[12] (about 1869) no important ore bodies had been found below a depth of 600 feet, and all the ore produced in the late sixties was obtained by reworking old ground or from newly discovered deposits in the upper levels. It is practically certain, therefore, that this specimen of rich ore came from depths of less than 600 feet.

This is a heavy ore in which the metallic minerals are dominant over quartz. A few pyrite grains are 4 millimeters across, but most of the mineral grains measure less than 1 millimeter across. Broken surfaces feel rough owing to the abundance of native silver. The ore minerals, named in approximate order of abundance, are sphalerite, quartz, galena, chalcopyrite, pyrite, argentite, native silver, calcite, and pale gold. All these minerals except native silver are clearly primary (hypogene), and the relations of argentite and gold to the base-metal sulphides are identical with those shown in figures 5 to 7. Therefore, all the gold and a considerable part of the silver of this ore are primary.

[12] King, Clarence, op. cit., pp. 170, 171.

sparsely but in relatively large crystals as much as 5 millimeters in diameter. The coarse portions are vuggy and obviously represent the last phases of mineralization. In these coarse-grained portions, usually between large quartz crystals but interlocking irregularly with smaller ones, occurs argentite intercrystallized locally with chalcopyrite, galena, and light-yellow gold. Polybasite in characteristic flat hexagonal prisms occurred in one vug. In the finer-grained portions of the ore the microscope reveals argentite in the same relations to the commoner ore minerals as in the specimens already described (figs. 5–7) though less abundant. Polybasite is abundant, however, and, as shown in figure 8, it bears the same relation to quartz and sphalerite as galena does. The contacts between polybasite and galena are sharp and regular and bear no relation to cracks and cleavages in the galena or to the contacts of polybasite with other minerals. The polybasite appears not to replace galena but to be contemporary with it and primary. The only replacement phenomenon observed in this specimen was a slight replacement of argentite by chalcocite along its contacts with other minerals.

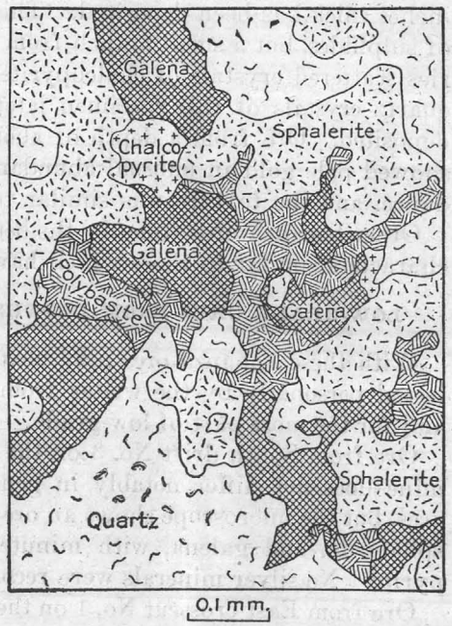

FIGURE 8.—Polybasite, probably primary, intergrown with galena, sphalerite, chalcopyrite, and quartz in ore from C. & C. mine, Comstock lode, East vein, 2,200-foot level. Camera lucida drawing.

7. Bonanza ore, East vein, Mexican mine, 2,500-foot level. In this ore pyrite was the earliest metallic mineral, and fractures traversing it are occupied by an association of sphalerite, galena, quartz, chalcopyrite, argentite, and gold. Some of the argentite occurs in the same manner as in the specimens illustrated in figures 5 to 7, but much also forms minute inclusions in galena and especially in sphalerite. Most of the argentite inclusions in galena are round or oval in outline and show no definite relation either in form or in distribution to the cleavage direction of the galena. Tarnishing the galena with hydrogen peroxide reveals a few very narrow replacement "rims" of probable polybasite between galena and other minerals and along contacts between two galena crystals. Minor peripheral replacement

of argentite by chalcopyrite was also noted. In vugs occur small mosslike masses of argentite and a few crystals of either polybasite or pearceite.

8. Rich ore, Sierra Nevada mine, depth 2,500 feet. Quartz-lined vugs contain crystals as much as 2 millimeters across of chalcopyrite, pyrite, and pearceite intergrown and obviously contemporaneous. On them and on the quartz later crystals of calcite have been deposited.

9. Ohpir mine, Hardy vein, depth 2,100 feet. This specimen is one of the few that show a banded structure. On fine-grained sulphide-rich ore of the usual character a layer of comb quartz about 1½ inches thick has been deposited. This quartz layer is nearly barren of sulphides, but a small branch from it cutting the sulphide ore carries scattered crystals of chalcopyrite and pearceite. On the coarse quartz crystals of this specimen later crystals of calcite have been deposited. Ore from a depth of about 2,200 feet in this same vein showed pale gold in unusual abundance and argentite in fair abundance, and the texture was similar to those shown in figure 6.

Other bonanza ores from depths between 1,000 and 2,500 feet show characters similar to those which have been described.

LOW-GRADE ORES FROM DEPTHS OF 2,500 FEET OR MORE.

With these bonanza ores may next be compared certain ores collected personally by the writer from depths of 2,500 feet or more, and for the most part of low grade.

Ore from South drift No. 3 on the 2,500-foot level of the Mexican mine does not differ notably in general appearance from the rich ores, but the microscope shows an ore composed essentially of quartz, sphalerite, and galena, with minute amounts of chalcopyrite and pyrite. No silver minerals were recognized, even under high power.

Ore from East crosscut No. 1 on the 2,700-foot level of the Mexican mine, said to average about $25 a ton, consists mainly of chalcopyrite, quartz, sphalerite, and galena, with rare pyrite. In a very few places minute amounts of argentite were noted intergrown with galena or as inclusions in sphalerite, but they are exceedingly rare.

Ore collected from the Union mine, on the 2,600-foot level, shows quartz, sphalerite, galena, pyrite, and rare chalcopyrite intergrown in the same manner as in the rich ores, but no silver minerals could be recognized.

SHALLOW BONANZA ORES.

Ores from the upper portions of the Comstock lode are now very difficult to procure, but the collections of G. F. Becker afforded several specimens of such ores for study.

1. Belcher bonanza. Through the courtesy of Mr. Herbert Hidden, of Virginia City, a small specimen from the Belcher bonanza, very

rich in both gold and silver, was obtained for study. According to Becker's longitudinal projections of the lode[11] the Belcher bonanza extended from a depth of about 75 feet to a depth of about 350 feet. The exact place of origin of the specimen is uncertain, but it presumably came from this ore body or was obtained at no great distance below it.

The small specimen, 1 inch across, though not stained with iron oxides is very porous in places, evidently as an effect of the solvent action of descending mine waters. The ore minerals are quartz, pyrite, chalcopyrite, sphalerite, galena, argentite, gold (light colored), native silver, and polybasite. There is a transition from fine-grained ore rich in sulphides to coarser ore rich in quartz, but both types show all the minerals listed above except polybasite, which is present only in the coarser portions. With the exception of native silver and polybasite the ore minerals are intercrystallized in the same manner noted in the deeper bonanza ores and illustrated in figures 5 to 7. Argentite is abundant even in the finer-grained portions of the ore, is related to the other minerals in identically the same fashion as galena, and is believed to be primary (hypogene).

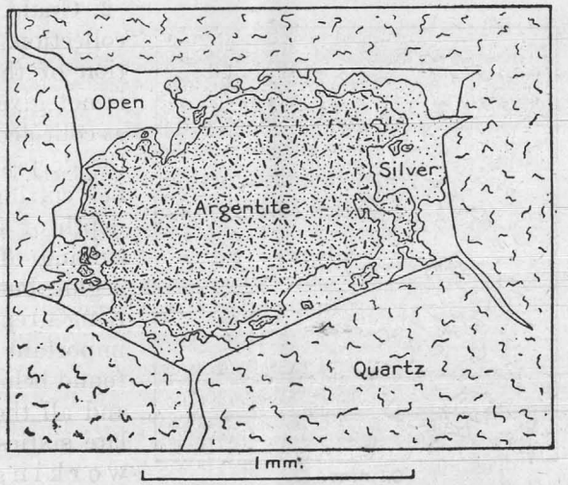

FIGURE 9.—Primary (?) argentite in small quartz-lined vug peripherally replaced by native silver, in shallow ore from Belcher bonanza, Comstock lode. The silver is believed to be a deposit from descending solutions. Camera lucida drawing.

In the more porous portions of the specimen, particularly the coarse-grained portions, native silver occurs associated exclusively with argentite and bearing the relations to it illustrated in figures 9 and 10. Where sparsely developed the silver lies mainly along the contacts between argentite and quartz which borders it, or adjacent to open spaces developed along such contacts, as is shown in figure 9. The contacts between argentite and silver, in marked contrast to those between argentite and galena, are exceedingly irregular, as shown in figure 9 and on a larger scale in figure 10. Such relations clearly indi-

[11] Becker, G. F., op. cit., atlas sheet 11.

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PROPYLITIZATION AND RELATED TYPES OF ALTERATION ON THE COMSTOCK LODE.

ROBERT COATS.

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ABSTRACT.

Descriptions of several occurrences of propylitized andesites are reviewed, including the original descriptions of "propylites." The principal explanations that have been offered for propylitization are: (*a*) dynamometamorphism; (*b*) autohydration; (*c*) origin through post-volcanic activity, generally by vein-forming solutions. The general geology of the portion of the Comstock district pertinent to the discussion is reviewed. The unaltered andesites are pyroxene-amphibole andesites. There are three principal types of alteration, deuteric, propylitic, and zeolitic. The deuteric is probably due to water vapor contained in the rock at the time of its crystallization. The propylitic appears to be due to heated solutions given off by a later intrusive. The zeolitic is apparently associated with vein-forming agencies.

INTRODUCTION.

MOST processes of hydrothermal alteration have been named from the characteristic mineral developed by them. The name thus comes to express the concurrence of two factors, process and material, rather than process solely. The term propylitization has been derived otherwise, but has the same limitations. Propylites are altered andesites. The degree and type of alteration present in rocks that have been described as propylites vary widely, however, as shown by a review of the literature. Between 1933 and 1937 the writer had occasion to study one of those occurrences of altered andesite to which the name propylite was earliest applied, and which might be said to be, in a measure, the "type locality" for propylitization—the Comstock Lode. Many of the rocks studied in thin section were taken, as nearly as possible, from the original localities of the propylites described by

Zirkel in the reports of the 40th Parallel Survey. These original propylites are here re-described, and upon the new descriptions is based a proposed definition of propylitization.

The origins suggested for propylitic alteration are reviewed briefly, and it is shown that no one of them is strictly applicable to the Comstock Lode. In all probability, similar end products may be produced by solutions having quite different origins.

REVIEW OF PREVIOUS WORK.

Under this heading the descriptions of propylitized rocks, their relationships to volcanic and tectonic phenomena, and the origins suggested are discussed. Lindgren [1] and Schwartz [2] have summarized American literature so well that this review will concern itself chiefly with foreign descriptions.

Descriptions of Propylitic Alteration.

The geologists who first examined the Tertiary ore deposits in the volcanic rocks of Eastern Europe learned to recognize a rock resembling somewhat the normal andesite, but differing from it in habit and superficial appearance. During the middle of the last century, similar rocks were found in many famous mining camps of the North American Cordillera.

von Richtofen,[3] who had studied the ore deposits of Hungary as well as those of the Comstock Lode, christened the rock in question "propylite" to express his belief that it was the precursor of all the volcanic rocks, *i.e.,* that it inaugurated Tertiary vulcanicity, since pre-Tertiary rocks at that time were not considered volcanic.

Zirkel,[4] who identified the rocks collected by the 40th Parallel

[1] Lindgren, W.: Metasomatic processes in fissure veins. Trans. A. I. M. E. 30: 579–689, 1900.

[2] Schwartz, G. M.: Hydrothermal alteration of igneous rocks. Bull. G. S. A., 50: 195–197, 1939.

[3] von Richtofen, F.: The natural system of volcanic rocks. Mem. Cal. Acad. Sci., 1: 22, 1868.

[4] Zirkel, F.: United States Geological and Geographical Survey of the 40th Parallel, p. 83, 1873.

Survey, generally followed the identifications of von Richtofen. With the exception of the diorite intrusion of Mt. Davidson, which was regarded as pre-Tertiary, the entire Virginia Range was regarded as having been covered by "an outflow of propylite."

Zirkel summarizes the following properties of propylites, as distinguished from andesites: Greenish gray groundmass, structure resembling diorite porphyry, the presence of scattered hornblende dust, the lack of glass inclusions in plagioclase, and of glass in the groundmass, the prevalence of epidote, the rarity of augite, the predominance of green rather than brown hornblende.

Becker,[5] however, determined as green chlorite much that was identified by Zirkel as hornblende. He came to the conclusion that

> the mineralogical composition and structure of the propylites of the Washoe district in their original state were identical with those of certain fresh rocks found in the same region, namely, granular diorite, dioritic porphyry, diabase, hornblende andesite and augite andesite. The great and misleading similarity of the propylites to one another is due not to original constitution, nor to their geological relations, but to the identity of the decomposition processes to which they have all been subjected.

Lindgren[6] in 1900, quoted the definition given by Rosenbusch that propylitization consisted in a loss of the glassy habit of the feldspars, the chloritic alteration of the hornblende, biotite and pyroxene (commonly with the intermediate stage of uralite), and also in the alteration of the normal groundmass into a holocrystalline granular aggregate of feldspar, quartz, chlorite, epidote, and calcite, commonly with a considerable development of sulphides, generally pyrite.

B. von Inkey[7] emphasized the alteration of hornblende and pyroxene to chlorite and carbonate. Biotite and feldspar may be quite fresh, according to him; pyrite is not essential. Schumacher's definition did not differ greatly from this.

[5] Becker, G. F.: Geology of the Comstock Lode. Mon. III, U. S. Geol. Surv., p. 88, 1882.

[6] Lindgren, W.: *op. cit.*, p. 585.

[7] von Inkey, B.: De la Relation entre l'Etat Propylitique des Roches Andesitiques et Leur Filons Mineraux. Compt. Rend. Cong. Geol. Int., X. Sess., 1: 501–517, 1907.

Lazarevic[8] divided propylitization into two types: (*a*) the zeolitic, corresponding with that described by Schumacher and von Inkey, except that the presence of zeolites is considered essential, and (*b*) the pyritic, in which the feldspars are sericitized and kaolinized, and much pyrite is added, together with some alunite.

T. Kato[9] was apparently the first to recognize the albitization of plagioclase as an essential feature of propylitization.

Bürg,[10] in 1931, reviewed propylitization and other types of alteration with specific reference to the occurrences at Brad, in the Siebenbürgen. Because of the looseness that has crept into the usage, Bürg prefers to use the phrase "grünsteinartige Andesitfacies" instead of propylite. His definition corresponds with that given by Schumacher. Megascopically he recognized as characteristic: (*a*) the loss of the original trachytic character with the formation of a tough rock with conchoidal fracture, (*b*) disappearance of porphyritic structure due to the alteration of the dark constituents, (*c*) greenish color of the rock.

Krusch[11] also worked at Brad. He recognized as propylitization the alteration of the rocks to become greenish, duller, and more or less impregnated with pyrite. New minerals are calcite, sericite, chlorite, epidote, quartz, etc. Pyroxene and amphibole are first altered completely to chlorite whereas the feldspars remain rather fresh. The propylite of Brad is like that of other young gold-silver veins, except that the latter have, in general, suffered a more complete alteration of the feldspars. This,

[8] Lazarevic, M.: Die Propylitisierung, Kaolinisierung, und Verkieselung und ihre Beziehung zu den Lagerstätten der propylitischen jungen Gold-Silbergruppe. Zeits. f. Prakt. Geol., *21*: 345–361, 1913.

[9] Kato, T.: Mineralization sequence in the formation of the gold-silver veins of the Toi Mine. Jap. Jour. Geol. Geog., *9*: 7–86, 1931.

Idem: Last Stage of Magmatic Differentiation as represented by Tertiary Gold-Silver Veins. Compt. Rend. Cong. Geol. Int., XV. Sess., *2*: 9–12, 1931.

[10] Bürg, G.: Charakteristic der grünsteinartige Andesitfacies, ihre Ursachen und Beziehungen zur Kaolinisierung und Verkieselung. Zeits. f. Prakt. Geol., *39*: 161–173; 187–192, 1931.

[11] Krusch, P.: Die Goldgänge der Rudaer 12-Apostel-Grube bei Brad (Siebenbürgen). Zeits. f. Prakt. Geol., *44*: 1–55, 1936.

however, is only a qualitative difference, since the alteration of the feldspars at Brad had begun, but was not completed.

Schwartz [12] has recently reviewed exhaustively the various types of hydrothermal alteration of igneous rocks. He regards propylitization as being characterized by the formation of chlorite and epidote. He quotes Kemp's definition of propylite as "the alteration of igneous rock in which hydrous magnesian alteration products are important and are associated with epidote and carbonates."

Relationship of Propylitization to Volcanic and Tectonic Phenomena.

Propylitization has generally been regarded, in this country at least, as a phenomenon spatially related to vein fractures, and generally caused by vein-forming solutions. However, several authors have noted a lack of such spatial relationship, and not a few have attributed the alteration to other causes.

B. von Inkey [13] early remarked on the regional character of propylitization, as compared with the kaolinization, which was clearly due to vein-forming solutions.

Lazarevic [14] noted that the propylitized rocks in areas studied by him showed neither signs of dynamometamorphism, nor dependence on zones of crushing. The degree of propylitization does not increase with approach to the veins. The propylitic alteration occurs over large areas where no veins are known, and the veins are found in fresh andesite.

Schneiderhöhn [15] mentioned the regional character, and announced that propylitization is older than the ore-formation and older than the alteration of the immediately adjacent country rock of the ore.

Bürg [16] noted that, at Brad, the volcanic necks are each uni-

12 Schwartz, G. M.: *loc. cit.*

13 von Inkey, B.: *loc. cit.*

14 Lazarevic, M.: *loc. cit.*

15 Schneiderhöhn, Hans: Die jungeruptive Lagerstättenprovinz in Serbien, Siebenbürgen, Ungarn und dem Banat. Centr. f. Min. Abt. A.: 404–406, 1928.

16 Bürg, G.: *loc. cit.*

formly, but to differing degrees, attacked by this type of alteration.

Krusch,[17] working in the same region, noted that there was no propylitic zone corresponding to vein distribution, but extensive propylitization over a wide area. Krusch also pointed out that no propylite arising from dynamometamorphism is known, and known dynamometamorphic rocks differ from propylite.

Kato,[18] in reviewing the features of the epithermal deposits in Japan, noted that the alterations are commonly so widely developed that they must be explained as having been accomplished by solutions derived from a more or less deep seated source, and permeated or diffused through the overlying rocks.

Campbell,[19] in discussing the alteration at Tonopah, noted that the earlier propylitic alteration was widespread, and antedated the actual ore deposition.

Lindgren,[20] discussing propylitic veins, mentioned the widespread character of the alteration at Pachuca and Silver Cliff, Colo.

ORIGIN OF PROPYLITIC ALTERATION.

Examination of the literature shows that the explanations offered for the origin of propylitic alteration have varied widely. In part these variations reflect the variation in nature of the process so named, in part, variations in opportunities for observation.

The various explanations have been well summarized by Bürg.[21] Propylite was considered by von Richtofen, Doelter, and Weinschenk as an independent rock, while Becker, Szabo, Kock, and von Inkey considered it as an alteration of andesite or dacite. Bürg classified the explanations that have been of-

17 Krusch, P.: *loc. cit.*

18 Kato, T.: Some characteristic features of the ore deposits of Japan, related genetically to the late Tertiary volcanic activity. Jap. Jour. Geol. Geog., 6: 31–48, 1928.

19 Campbell, Ian: Some inter-relations between phases of alteration and types of rocks in the Tonopah mining district, Nevada. Bull. G. S. A., 44: 164, 1933.

20 Lindgren, W.: *loc. cit.*

21 Bürg, G.: *op. cit.*, p. 161.

fered for the origin of propylitic alteration as follows: (*a*), origin through post-volcanic activity (Szabo, Inkey, Rosenbusch, Becker—to whom might well be added Lindgren, Kato, and most American writers); (*b*), origin through dynamic action (Schumacher); (*c*), origin through autohydration (Balfy, Niggli, Schneiderhöhn, Bürg).

Lazarevic [22] considered the zeolitic propylitization to be due to carbon dioxide, the pyritic to hydrogen sulphide gas. He believed propylitization to be due to post-volcanic action on normal rocks, although not an alteration proceeding from the veins.

Kato [23] thinks that propylitization represents the first stage of hydrothermal mineralization or the first stage of the post-volcanic process.

Bürg [24] attributes the formation of the "grünsteinartige Andesitfacies" to autohydration. Hydrogen sulphide could not have been important, judging from the small quantity of pyrite formed. The alteration of the ferromagnesian minerals to chlorite in rocks, the feldspars of which remain fresh, indicates, according to Bürg, the agency of water vapor rather than carbon dioxide. A relatively early period of alteration is indicated by the presence of inclusions of chloritized pyroxenes in fresh biotite. He thought that the "greenstone-like andesite facies of the pyroxene-amphibole andesite must be considered as an autometamorphism during the cooling of the rock." The temperature conditions of alteration are about the same as the existence region of hornblende, namely, 500 to 1000° C. Pressure is the essential factor, the autohydration begins at the point where the water-free silicates are no longer stable in the water-rich magma. The difference between andesite showing this alteration and that which does not is due entirely to the conditions of consolidation. At lower temperatures, feldspars begin to be altered. This is characteristic zeolitic propylitization.

[22] Lazarevic, M.: *op. cit.*, p. 350.

[23] Kato, T.: Mineralization sequence in the formation of the gold-silver veins of the Toi Mine, Idzu Province. Jap. Jour. Geol. Geog., 9: 73–74, 1931.

[24] Bürg, G.: *op. cit.*, p. 173.

Krusch[25] inclines to the Stelzner-Bergeat explanation of propylitization as due to the extensive penetration and soaking by gases of a magma not yet entirely solidified. This differs from the usual explanation only in the point of the time when the action took place. At Brad, according to Krusch, the great gas-richness of the magma caused such soaking to begin immediately after the solidification of the magma and to continue after the formation of fissures and their filling.

Schneiderhöhn[26] also considered propylitization as a sort of autohydration, beginning either directly after the solidification or in part before the solidification of the rocks. It is due to the volatile constituents of the rocks, which were set free by crystallization, and is thus analogous to many chloritic greenstone formations in diabase, to serpentinization of olivine rocks, much epidotization, and others.

It may thus be seen that, although in many localities propylitization is directly related to metalliferous lodes, in others it appears to be more widely distributed. In places it is related to surfaces of flows or contacts of intrusives, or to widespread fracture systems. Most American authors have considered propylitization to be due to hydrothermal alteration by vein-forming solutions; European authors have described as propylitization similar types of alteration, some of which appear to be due to autohydrothermal or deuteric action, possibly also to dynamometamorphism, as well as to post-volcanic processes in the widest sense.

ALTERATION IN THE COMSTOCK DISTRICT.

Outline of Geology.

An understanding of the nature of the alteration along the Comstock Lode presupposes an acquaintance with the distribution and relations of the chief rocks concerned. The two principal rock bodies involved are the Alta andesite, a series of pyroxene and hornblende andesite flows and breccias more than 2000 feet thick, with interbedded rhyolitic tuff, and the Davidson

25 Krusch, P.: *op. cit.*, p. 7.

26 Schneiderhöhn, Hans: *op. cit.*, pp. 404–406.

diorite stock, intrusive into the volcanics and pyroclastics. These rocks are cut by the Comstock fault, striking roughly north-northwest in this area, and dipping about 35° eastward. The throw of the fault movement was about 2400 feet before mineralization, and about 1600 feet subsequently. No diorite is exposed in the eastern, or hanging-wall, block, at levels reached by accessible workings, although porphyritic rocks, possible offshoots of it, are present. The contact of the diorite stock flares outward irregularly with depth, so that the footwall of the fault, over the most productive portion of its length, is diorite. The Sutro Tunnel and its laterals permit access to the hanging-wall block at an elevation of about 4500 feet above sea level. The elevation of the surface on the hanging-wall block ranges from about 5500 to 6100 feet above sea level, over most of the area; that of the footwall from 6000 to 7900 feet.

The Alta andesite series has a variable attitude. In the hanging-wall block it dips generally westward, as shown by the obscure flow-banding and the attitude of the interbedded pyroclastics, at angles ranging from 15 to 50°. In the footwall, dips are more irregular, but are generally steeper, and reversals of dip may be observed.

Character of the Alta Andesite.—The Alta andesite is a series of andesitic flows and intercalated andesitic breccias. Both matrix and fragments of the breccias are chiefly andesitic, although accidental fragments are present. Where fresh, the breccias and flows may be readily distinguished; a relatively slight degree of alteration renders the distinction very difficult. Since the nature and distribution of the alteration are more readily studied in the flows than in the breccias, the alteration of the flows will be considered exclusively in the following discussion.

Megascopically, the flows display certain differences. The lower flows seem to be generally gray to black in color, with large to medium-sized prismatic crystals of dark hornblende. The higher flows appear to have a less crystalline groundmass, a larger proportion of plagioclase phenocrysts, slightly smaller hornblende crystals, and more plentiful magnetite.

Petrography of the Alta Andesite.

Under the microscope, it may be seen that the texture of the flows is actually seriate, rather than strictly porphyritic, all sizes of crystals being present, from the largest down to the microlites of the groundmass.

In the freshest specimens the plagioclase phenocrysts, commonly up to two or three millimeters in size, make up as much as 30 per cent of the rock. In composition they vary from An_{50} to An_{64}. The ferromagnesian minerals are hypersthene, diopsidic augite, and hornblende; pigeonite is rare. The presence of hypersthene was difficult to establish in most sections, since it is almost never found fresh in these rocks. Nearly every section, however, shows bastite pseudomorphs, commonly with the simple prismatic form that seems to characterize the rhombic pyroxene. All ferromagnesian minerals range in quantity from one to five per cent, rarely slightly more. The augite is commonly in irregular prisms and rounded grains, seldom larger than 1 mm. Where fresh it is commonly clear, non-pleochroic, or only slightly so in greenish tones. It shows an extinction angle of about 45° on (010), a double refraction of about 0.30, and a slight inclined and rhombic dispersion, indicating the diopsidic character. The axial angle is about 60°. The hornblende is typically a variety pleochroic in greenish-brown and yellow-green tones. The extinction angle on the clinopinacoid varies from 13° to 15°. A typical pleochroism formula is: X = pale yellow, Y = olive green, Z = greenish brown. The hornblende commonly occurs in prisms up to 3 or 4 mm. in length. It shows the dark resorption border, typical of extrusives, of magnetite granules, in which may sometimes be detected grains of augite.

The chief accessories are apatite, magnetite, and rare zircon. The apatite is characteristically pseudo-dichroic, the E direction being dark brown, the O direction gray, due to the presence of oriented inclusions in the apatite.

The groundmass of the fresh andesite has a texture ranging from hyalopilitic to pilotaxitic. The glassy mesostasis has generally crystallized to irregular areas of quartz, with patchy

extinction. It encloses microlites of plagioclase varying in composition from oligoclase andesine to basic andesine, with granules of augite and of magnetite.

Types of Alteration.

Deuteric.—The most widely distributed type of alteration in the Alta andesite is the conversion of the rhombic pyroxene to pale green pseudomorphs of bastite. So universal is this phenomenon that the existence of rhombic pyroxene in these rocks might be considered doubtful. The evidence for it includes: The simple outline of the pseudomorphs, as contrasted with the stubbier prisms, showing more numerous forms, of the augite; the lack of aluminous or calcareous minerals with or in the bastite; the occasional occurrence of these pseudomorphs with jackets of fresh augite, resembling the common type of augite jacket on a hypersthene core. This conversion of rhombic pyroxene to bastite is found in rocks that otherwise show no trace of alteration. It is not confined geographically or tectonically in its occurrence, nor does it show any relationship to cooling boundaries, as far as could be observed.

This type of alteration is interpreted by the author as being approximately equivalent to the autohydration of some European authors.

Propylitic.—The most widespread type of secondary alteration is shown by the rocks that were originally described as propylites. They are well exposed in the footwall block, particularly to the north and south of the outcrop of diorite and the zone of thermal metamorphism surrounding it. Megascopically, the first effect of this type of alteration is the emphasizing of the feldspar phenocrysts, by rendering them less translucent. The rock loses its dark gray or bluish gray color and becomes greenish gray. Further alteration reduces the entire rock to a dull greenish mass, the ferromagnesians and feldspars being both completely altered. The conchoidal fracture possessed by the fresh rock is lost; the rock acquires a fracture like that of under-burned brick.

The propylitic alteration is characterized microscopically by

the presence of epidote, chlorite, and albite. It has resulted, where mild, in the partial replacement of labradorite by veinlets of albite, flakes of sericite, calcite, and granules of epidote. The hornblende has been converted to calcite, chlorite, and magnetite. The color of the bastite replacing the rhombic pyroxene has changed from yellowish green to bluish green. The groundmass, once an allotriomorphic aggregate of pyroxene and plagioclase, has been largely replaced by chlorite and albite, calcite, and some quartz. Alteration of this intensity is not sufficient to destroy the dark color and relatively fresh appearance of the rock.

Specimens that have acquired the dull green color of the typically propylitized rocks show feldspars completely altered to epidote, clinozoisite, and albite. In the areas once occupied by ferromagnesian minerals, the chlorite and calcite appear to have been replaced in part by epidote, which has derived part of its iron from some of the magnetite. The plagioclase of the groundmass is completely albitized and epidotized, with retention of the form and albite twinning. There is developed a considerable amount of secondary quartz in clear grains, scattered through the groundmass; also coarser epidote, with which are associated clear secondary quartz and albite.

Specimens taken from the Sutro Tunnel level, near the Comstock Lode, differ from those taken on the surface in the footwall, and described above, chiefly in that the epidote does not appear to be developed in as large or as clear grains in the former. The minerals present are similar.

More remote from the footwall, the alteration is similar in type, but less intense. In nearly every rock in which the feldspar is at all altered the ferromagnesian minerals are as highly altered, but feldspars may be quite fresh in sections in which ferromagnesian minerals are converted completely to chlorite, calcite, and quartz.

As seen in surface exposures, the propylitization is much better developed on the footwall side of the Comstock Lode than on the hanging wall. One reason for this is that the hanging wall was more intensely fractured before mineralization and has suffered more widespread alteration of the types associated with

he attributes the alteration to hydrothermal metamorphism by the Davidson diorite.

CONCLUSION.

It has been shown that the term propylitization has been extended to cover a variety of different types of alteration, and that these types of alteration have been produced in several different ways. By no means all propylitic alteration is to be attributed to hydrothermal alteration by vein-forming solutions. The writer believes that the term should be applied to rocks essentially resembling the original propylites, which are altered andesite, containing epidote, comparable in size with the feldspars, and albite, replacing plagioclase; and secondary chlorite, calcite, and epidote, replacing ferromagnesian minerals. The occurrence of pyrite is not necessary to the definition of propylite. The somewhat similar, less intensely altered basic or intermediate volcanics commonly found in association with epithermal ore deposits might well be termed *epi-propylites*.

U. S. G. S.,
WASHINGTON, D. C.
July 6, 1939.

mineralization and therefore a more intense attack by supergene alteration. This latter has created near the lode, especially on the hanging wall side, a wide belt of bleached and stained rock that separates the intensely propylitized rocks of the footwall from the nearest recognizable outcrops of andesite in the hanging wall, which have suffered relatively slight propylitization. In addition to this effect, the considerable movement on the Comstock fault has brought to light rocks on the footwall side that were more deeply buried at the time of alteration than those on the hanging wall side, now at the same level. These differences between foot- and hanging-wall rocks, together with the relative scarcity of mine workings in the footwall, are responsible for the observation of Lindgren [27] that epidote is more common on the surface than underground.

The propylitization does not appear to bear any relationship to cooling surfaces or flow tops or bottoms. In many places in the footwall it may be observed to increase in intensity in the vicinity of systems of steeply dipping fractures. These fracture zones are more or less parallel with the main axis of the Washoe or Virginia Range; the fractures are irregular in strike and dip when examined in detail, are spaced two or three inches, or less, apart, show slight separation of the walls, and no movement of one wall relative to another, since there is no slickensiding of walls. Some show small veinlets of quartz, free from metallic minerals, and of hematitic jasperoid-like material, apparently fine-grained quartz and hematite. They show no relationship to known faults, or to zones of bleaching, silicification and iron-staining. In detail, the alteration shows no relationship to the contact zone of the Davidson diorite; in general, the degree of intensity of alteration declines with distance from the intrusive; some highly altered areas are remote from known outcrops of the intrusive. The diorite and the thermally metamorphosed andesites and tuffs of the contact zone have, however, been propylitized to some extent.

The origin of the propylitic alteration will be discussed in more detail on a following page.

[27] Lindgren, W.: *op. cit.*, pp. 578–692.

Zeolitic.—Another type of alteration, less widespread in its distribution, which is seemingly controlled by mineralized fractures, may be a late phase of the propylitization, although the spatial distribution suggests that it is related to solutions that followed different channels. Because the alteration of this type is in many places superimposed on the propylitic rock, it is difficult to find specimens that show zeolitic alteration without propylitic.

The chief characteristic of this type appears to be the development of albite, with more or less zeolite, which is sometimes identifiable as natrolite, in the plagioclase phenocrysts. Locally, as at the top of South Twin Peak, near the Lode, the plagioclase may be altered to calcite, albite, and natrolite, without any perceptible alteration of hornblende and clinopyroxene. The selective effect of this type of alteration on the feldspars rather than the ferromagnesian minerals helps to distinguish it from the propylitic. Where it attacks rock that has been previously propylitized the only sign of its presence might be the occurrence of natrolite. The distribution of pyrite appears to be more limited areally than that of zeolites, but otherwise seems to be related to this type of mineralization. Surface specimens rich in pyrite are not found, because of the thorough-going destruction of the rock minerals by the sulphuric acid released by the oxidation of the pyrite.

Other Types of Hydrothermal Alteration.—Some specimens of andesite from underground workings in the neighborhood of the Lode show replacement of the groundmass by poikiloblastic plates of gypsum enclosing remnants of anhydrite, evidently the original metasome.

In the immediate vicinity of the veins, the country rock has undergone a thorough-going silicification and sericitization.

There are thus present on the Comstock three types of alteration, rather similar in character. The earliest, or deuteric, type, is characterized by the conversion of orthopyroxene to bastite. The generally crystalline character of the groundmass may also be an effect of this. The most widespread type, propylitization, is characterized by the development of chlorite, epidote, albite, and

calcite, the ferromagnesians being more easily altered than the feldspars. The third type, zeolitization, is characterized by the development of natrolite in plagioclase, with albite and calcite, and by alteration of feldspar before the ferromagnesian minerals.

ORIGIN OF PROPYLITIC ALTERATION.

For various reasons, none of the three explanations most commonly offered for propylitic alteration seems applicable here.

Schumacher's suggestion that propylitization could be due to dynamic metamorphism is hardly applicable, since the most thoroughly propylitized rocks show no effect of stress, no crushing or granulation, no nortar structure or strain shadows.

There is little evidence to suggest that propylitization on the Comstock could be due to autohydration, because of the lack of relationship to original igneous structures, and because of its definite relationship to later fractures.

The widespread character of the propylitic alteration, and lack of spatial relationship to the vein fractures suggest that it was not due to vein-forming solutions. The lack of pyrite in highly propylitized rocks contrasts with the usual type of hydrothermal alteration in the vicinity of epithermal veins. The coarseness of the epidote in typical propylitized rock, as compared with the wall rock of the veins, and the development of albite from feldspar, both suggest solutions at rather higher temperatures than those usual in epithermal ore deposition. Taken together, the observations suggest to the writer that propylitization on the Comstock was due to hydrothermal alteration independent of, and probably antecedent to, the ore deposition on the Comstock Lode. The areal distribution of the propylitization on the Comstock suggests that the source of the solutions should be sought in a body of cooling igneous rock beneath the footwall block. This may have been a deeper portion of the Davidson intrusive. The writer does not believe it could be properly attributed to the now exposed portions of the Davidson stock, because of the alteration that these show. The conclusion of Calkins [28] is rather similar to this, as

[28] Calkins, F. C.: Igneous activity in the Comstock district, Nevada. Trans. Am. Geophys. Union., p. 262, 1938.

Mining Methods at Gold Hill, Nevada

A Description of the United Comstock's Underground Operations

By George J. Young
Associate Editor

PERIOD OF MINERALIZATION OF THE COMSTOCK LODE, NEVADA

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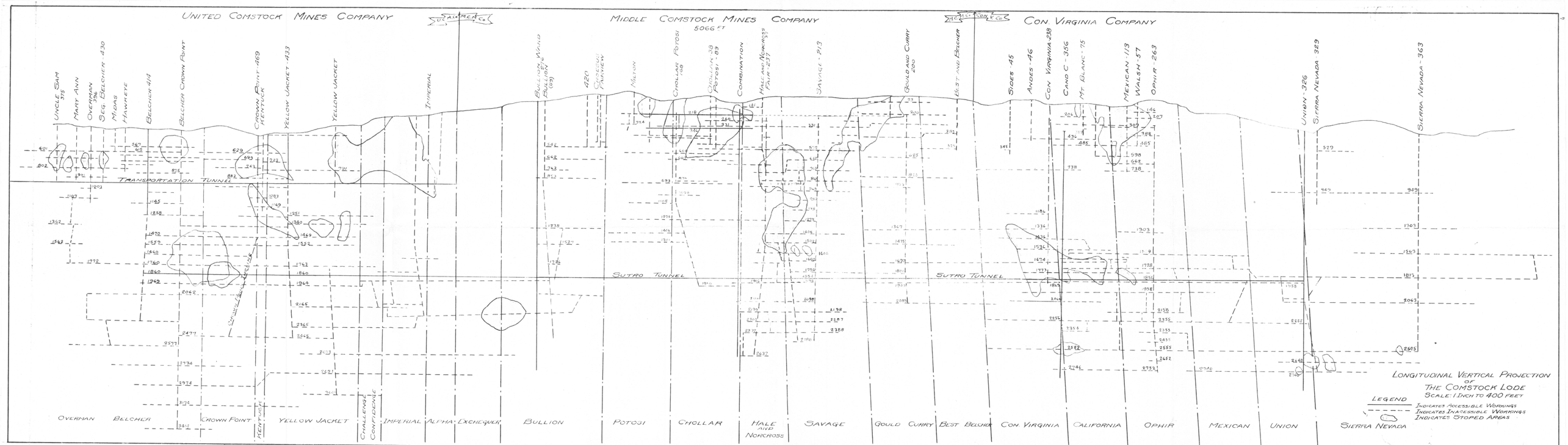
Vincent P. Gianella
University of Nevada, Reno, Nev.

The Comstock Lode, in western Nevada, was one of the most productive gold and silver deposits


UNITED COMSTOCK MINES COMPANY
MIDDLE COMSTOCK MINES COMPANY
5066 FT
CON. VIRGINIA COMPANY
UNCLE SAM 575
MARY ANN
OVERMAN 396
SEG BELCHER 430
MIDAS
HAWKEYE
BELCHER 414
BELCHER CROWN POINT
CROWN POINT 469
KENTUCK
YELLOW JACKET 433
YELLOW JACKET
IMPERIAL
BULLION MAIN
BULLION 609
420
CHALLENGE CONFIDENCE
MAYOR
CHOLLAR POTOSI 438
CHOLLAR 38
POTOSI 89
COMBINATION
HALE AND NORCROSS 237
SAVAGE 213
GOULD AND CURRY 200
BEST AND BELCHER
SIDES 45
ANDES 46
CON VIRGINIA 238
CAND C 356
MT BLANC 75
MEXICAN 113
WALSH 57
OPHIR 263
UNION 326
SIERRA NEVADA 329
SIERRA NEVADA 363
TRANSPORTATION TUNNEL
SUTRO TUNNEL
SUTRO TUNNEL
OVERMAN
BELCHER
CROWN POINT
KENTUCK
YELLOW JACKET
CHALLENGE CONFIDENCE
IMPERIAL
ALPHA
EXCHEQUER
BULLION
POTOSI
CHOLLAR
HALE AND NORCROSS
SAVAGE
GOULD
CURRY
BEST
BELCHER
CON. VIRGINIA
CALIFORNIA
OPHIR
MEXICAN
UNION
SIERRA NEVADA
LONGITUDINAL VERTICAL PROJECTION OF THE COMSTOCK LODE
SCALE: 1 INCH TO 400 FEET
LEGEND
INDICATES ACCESSIBLE WORKINGS
INDICATES INACCESSIBLE WORKINGS
INDICATES STOPED AREAS

Mail to
Mr. Wisser

to some extent by its owners and their lessees, and produced altogether 1100 tons of copper metal. They used the Mexican furnace with charcoal, losing a high percentage of copper, but their books show an extraction of 37% per each ton of ore smelted. This mine is situated on a strong ledge traceable the entire length of the two districts. The ledge has a north and south trend and dips about 70° to the east. The quartz was originally quartz porphyry. Porphyry of a later date than the original porphyry has flowed over and completely capped it. Besides altering the quartz porphyry in its character the dike has been no doubt largely responsible for the ore deposition. The quartzose mass lies on a quartz diorite foot wall and is paralleled on the west at a distance of about 1000 yards with a feldspatic porphyry dike. Copper veins are found along both contacts with the diorite.

At Puckdaw hill the belt widens into a large kidney and becomes ore bearing. A central ledge occurs carrying veins of varying thickness containing payable gold with slight copper values. There are many smaller veins paralleling these dikes and all on the east side dip to the west and those on the west dipping to the east, indicating a junction of all at some unknown depth below with the main central vein. The central vein at the surface shows a width of 10 to 20 feet. What is needed is capital, machinery and skill for these two districts to become producers.

While there are many veins that are practically free milling, the ores taken generally are smelting. The copper ores of Mancayan are somewhat refractory, but those of Suyoc contain magnesian lime in abundance in the gangue and very little base metals, and if mixed with the ores of Mancayan a very high per cent of extraction could be had.

There are about 100 claims located in these two districts, and nearly all show ore values and sufficient indications to encourage developments. The districts are on the headwaters of the Abra river, water power can be had in abundance and timber is plentiful. The only drawback at present is inaccessibility. Mancayan is about 55 miles from Candon on the coast, and all supplies and materials have to be brought in over a pack trail.

The climate is healthful and the surrounding country is fertile and the hills and mountains furnish fine grazing for stock.

Cervantes, the capital, 14 miles north of Mancayan, has an elevation of 1700 feet above sea level, Mancayan 3983, Tubuc 4540 and Suyoc 5518. With these elevations white men can work the year around, as well as in the States.

The Comstock Lode and Its Future.

The Comstock Lode at Virginia City, Nev., has ever since its discovery in 1859 to the present day been one of the most interesting mineral deposits known to the mining world, and it will continue to be of interest for years to come. In a little volume to be circulated at the Exposition at St. Louis, Mo., the following appears, written by G. McM. Ross, who is well qualified to describe the workings and metallurgical methods of the great Lode, having grown up with the industry. After an interesting historical sketch, the writer says:

The rich gold and silver ores were shipped to and sold in San Francisco, while experiments were being tried on the Comstock and in San Francisco on all sorts of processes and devices for the recovery of the values in gold and silver contained in the Comstock ores. The mining companies themselves undertook the reduction of their ores with an equipment whose magnificence was only equaled by its inefficiency. To this first work can be credited the imperfect and costly treatment of the Comstock ores that has lasted until the present day. Shrewd, hard-headed, practical men built mills for the reduction of Comstock ores, and, as a result of their joint efforts, the Washoe process was evolved. When this process had been established as the one best adapted for the reduction of the ores, the profits derived from milling were so large that powerful milling companies were formed, and any efforts at the milling of their own ores by the mining companies were effectually discouraged.

THE WASHOE PROCESS.—The Washoe process is the Americanized Mexican patio process and is used for the extraction of gold and silver ores in the following way: The ore is crushed in wet-crushing 5-stamp mortars to a fineness ranging from twenty to forty mesh; the crushed ore is settled in square tanks, set on the pan-floor levels; the finest of the slimes is settled in reservoirs outside of the mill. The crushed ore, when settled, is charged into fast-running grinding pans holding a charge ranging from one to two tons; the pans are either steam-jacketed or arranged to take live steam into the charge; the ore is kept at such a consistency as, with the motion in the pans, will keep the quicksilver, which is added to each charge of ore, in suspension in the charge. Chemicals are used in the process, usually bluestone and salt, and the ore worked hot. The treatment lasts from three to six hours in the pans that are finally discharged into settlers (a slower-motion pan to which large quantities of water are added) to insure the settling of the quicksilver with its charge of gold and silver in such a way that the pulp or ground ore will not settle; the pulp is slowly discharged from the settlers, the quicksilver recovered and strained to secure the gold and silver amalgam, which is usually ground in a clean-up pan to remove impurities, retorted and retorted; the resulting crude bullion is melted into bars of nearly fine gold and silver.

The mill arrangement and equipment is as follows: For ten stamps of 900 to 1000 pounds each four standard 2-ton pans are required, with two settlers and a slow-motion clean-up pan, retort, assay office, etc. The actual horse power required will be sixty; but, to provide for extra rock-breaking service, a modification of the process, etc., it will be well to provide 75 H. P. for the work. Such a mill will treat from thirty to forty tons of ore per day at a cost ranging from $3 to $7 per ton, depending upon the loss of quicksilver, cost of water, power, etc. In the treatment of the ore such a mill will use 50,000 gallons of water per twenty-four hours; about 50% can be settled and used over again when water is scarce and expensive. The following modifications of the Washoe process have been introduced: Plate and battery amalgamation is being used successfully. The free gold contained in the gold and silver ores is amalgamated and recovered from the mortars upon silvered copper plates that are used before the ore reaches the settling tanks; the ore is, after passing over these plates, treated in the same way by the Washoe process as the ores first referred to.

CONCENTRATION BEFORE AMALGAMATION.—In ores containing heavy sulphides it has been found that, by removing these sulphides before treating the ore in amalgamating pans, a higher percentage of the values is recovered at a reduced cost. Any type or kind of concentrator that will remove the sulphides can be used for the work.

THE COMSTOCK'S PRODUCT.—With this process established, the production of gold and silver bullion from Comstock ores was rapidly increased. In 1860 the yield was: Gold, $550,000; silver, $200,000. In 1861: Gold, $2,500,000; silver, $1,000,000. By 1864 the production had reached: Gold, $6,400,000; silver, $9,600,000. By 1869 the output of gold and silver had dropped to $7,405,578. From 1870 to 1877 there was a steady and rapidly increased product—in the last-named year, that of the greatest output, $14,520,614.08 being gold and $21,780,922.02 being silver. The total output of the Comstock mines in gold and silver to the end of 1902 is probably very close to $371,000,000. Of this sum there was about 60% silver, the remaining 40% being gold. These values were recovered; the losses are estimated at between $60,000,000 and $80,000,000; of this loss modern methods would have saved 70%.

THE MINING OF COMSTOCK ORE.—The discovery of the silver sulphides having been made by placer miners, it was some time before the nature of the lode was understood. The first ore was found in small westerly dipping veins that, on being followed, developed into great masses of ore that turned when nearing the easterly dipping foot wall, and the vein or fissure followed this wall to a depth of 3200 feet below the surface. In a short time after the discovery of the silver sulphides, the mining world was fairly represented on the Comstock by men interested in some phase of mining. Added to them were the speculators and gamblers. The result of their combined efforts was to cover the surface of the earth with hundreds of mining locations, as the speculators and gamblers soon discovered that mining claims had a speculative value. On the Comstock the main lode was soon outlined and reduced to ownership by many companies. Of these twenty-eight have maintained their organizations to the present time. The ore bodies of the main lode were so much larger and richer than anything found in the outlying mines that attention and work soon concentrated upon the mines of the main lode, notwithstanding the fact that to the east and west of the Comstock Lode ore of value was found in quantity which, under conditions less exciting than were brought about by the development of the main lode, would have been successfully worked, as it surely will be in the not distant future.

The high wages that were paid to the miners and mechanics on the Comstock was the magnet that attracted the most skillful of these men from the ends of the earth. The managers were thus enabled to meet the unusual difficulties of mining large bodies of ore, handling large quantities of water and opening up new ground where the temperature was unusually high. The quartz miners of the Comstock had penetrated the lode to a depth of 3000 feet within twenty years of the discovery of silver sulphides on the surface. Within that time the simple hand windlass had been superseded by more and more powerful machinery, until direct-acting hoisting engines of 1000 H. P. were being used. These engines were designed for work to a depth of a mile below the surface. A tunnel was started and connected with the lode from a point in the valley of the Carson river 4 miles distant, thus forming a new base of operations 1600 feet below the surface. Powerful pumping machinery was installed at various points along the lode, one such installation costing $1,000,000. After a splendid dash at attaining great depth, and but a partial development of these depths, that failed to bring forth a Bonanza, while being threatened on every side by known bodies of hot water, a retreat was ordered and 1700 feet of opened and partly developed depths were abandoned and the hands upon the Comstock's dial were rudely thrust back for at least a quarter of a century. The reason and excuse for this was the fact that no unity of interest had ever been acknowledged by those in control of the various mines or groups of mines on the Comstock, and even science failed to give a reasonably definite statement of what might be expected of the Comstock in depth.

A pump had been installed and operated under conditions that at that time had never before been encountered by an engineer; yet the pump was so perfect and efficient that, had a united effort been made by the principal mines of the Comstock, this pump could have been operated and the lower levels need never have been abandoned.

A vertical depth of 3300 feet was reached before the lower levels were abandoned. It was several years before the water again rose to the level of the drain tunnel, 1700 feet above. During these years millions of dollars were extracted from ore bodies that formed the margins of the old Bonanzas on the Comstock. It is one of the remarkable features of these ore bodies that they begin and end in quartz bodies—quartz being the gangue or matrix in which the ore is found, the ore forming a rough central core or lens surrounded by quartz, carrying but little ore. In Bonanza days, and during the mad rush to extract a great number of tons per day, the heart of the Bonanza was literally torn out of its quartz body, and in every instance where a Bonanza was found and mined it has paid to mine the ground again. It is also true that, in several instances, a greater tonnage was extracted during the second period of mining than during the first, even when it was not possible to mine the ground thoroughly.

By 1898 the conditions on the Comstock were cheerless and nearly hopeless. Many of the mines were practically abandoned; ruin and decay were the prominent features. At this period, a few men, to whom failure and defeat were unknown terms, with tireless energy and boundless faith in the Comstock, worked at, and succeeded in getting together, the loose ends of the many interests that centered in the Comstock and in convincing those in control of those interests that to save the Comstock from complete abandonment a united effort must be made to recover the lower levels of the Lode. These men were so far successful that a provisional and temporary union of all Comstock interests was formed by twenty-eight mines entering into and forming the Comstock Pumping Association. The operations of this association were successful. The original plan succeeded in recovering 400 feet in depth of the flooded levels, in the discovery of an ore body, and in the re-establishment of sufficient confidence in the Comstock mines to warrant a general resumption of work along the Lode.

The device used in draining the Lode is a modified hydraulic elevator designed to use water under a head of 2000 feet and over. Using water under such great pressure brought forward problems in hydraulics that are not yet solved. The advantages of the system are so great as to economy of space and first cost that every feature of the system deserves the most careful study, with the view of attaining final perfection and highest possible efficiency. Before $100,000 had been expended in this system, more water was discharged into the drain tunnel at one time by it than had been discharged by the $5,000,000 worth of pumps formerly in operation on the Comstock Lode. Shortly after this system had been in fairly successful operation it was decided to operate the mines of the Comstock by electric power. A company was formed that secured contracts for power paid in advance of delivery and the power plant was built. The plant is now in successful operation, delivering power that is used in mining, pumping, milling ore, and for lighting, from a generating station at a point on the Truckee river 33 miles distant from the Comstock Lode.

THE FUTURE OF THE COMSTOCK.—This statement is not intended to be prophetic. The author has knowledge of Comstock history, and of the strange freaks it has produced in the lives of men and in the condition of things. In these actions and reactions, Bonanzas and Borrascas have played almost equal parts. The Bonanzas have deluged men with more money than they could count; the Borrascas have wafted our men and women to other scenes where fame and fortune became theirs.

The most striking fact in the history of the Comstock is revealed by a study of the working maps. While it is true that a vertical depth of 3300 feet has been reached on a vein with an average dip of 45° to the east, and that hundreds of miles of tunnels and drifts have been run, it is equally true that barely 20% of the lode above the 1600-foot level has been prospected, that to-day good ore is being extracted within a few feet of the surface at many points, and that millions of tons of ore will yet be profitably worked from the croppings of the lode. Below the 1600-foot level 7% would be a very liberal allowance for the prospected or developed ground of the Comstock Lode.

The second fact is that no modern complete milling

plant for the reduction of ores exists on the Comstock. It is true that first-class modern work has been done, and that ores are now being reduced at a fraction of former costs, but the credit for this work is due to individual effort, and not to the direct action of any mining company. The data now available is conclusive as to what percentages of the values of Comstock ores can be recovered. The unaltered ores, treated by plate amalgamation and concentration, yield from 60% to 80% at once. Of the remaining 20% to 40% of the value, there can be recovered 60% to 70% by cyanide treatment. Of the other Comstock ores nearly equal results can be obtained and at not greater cost. Our neighbors in California and to the east are treating ores in this way, crushing, amalgamating, concentrating and cyaniding the tailings in quantity for $1 per ton of ore treated.

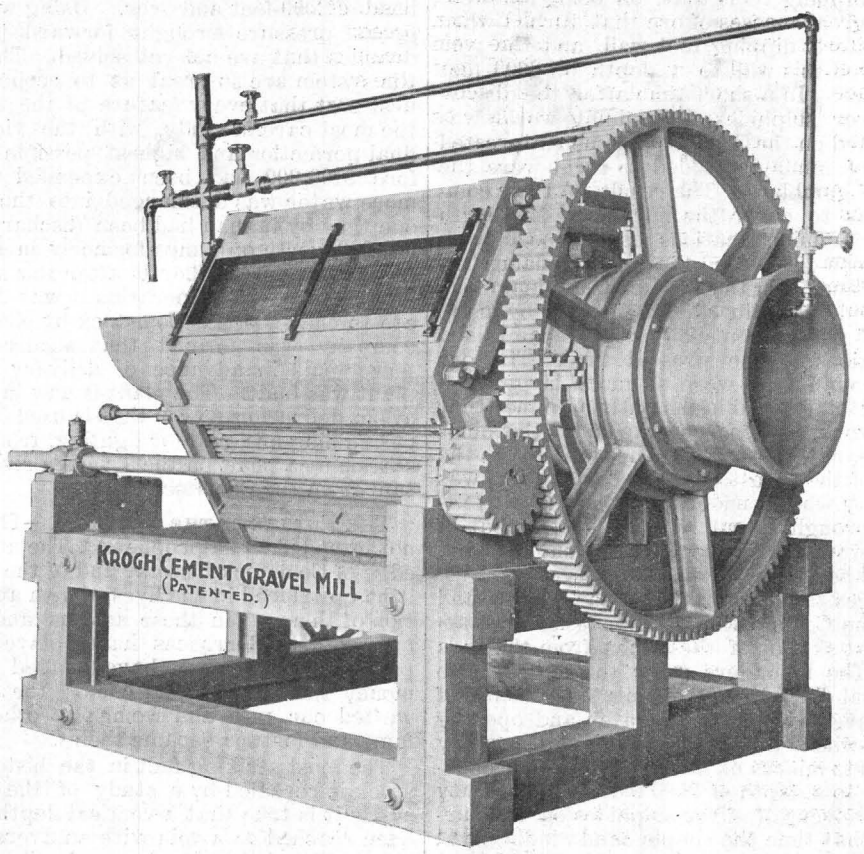
From these facts, it is reasonable to assume that the law governing the occurrence and recurrence of ore bodies will be discovered and the discovery published for the benefit of mankind. The low costs of mining and milling, so general throughout the world, will at least be duplicated on the Comstock. Those in control of the mines will become students of the great Lode.

Those who have the best information of the Comstock Lode can safely say that there is no mining field known in the world that offers inducements so great and lasting to the student, the capitalist, the mining engineer, or the speculator. If the man exists who combines in himself the best of these qualities, the Comstock is the field provided by nature for the full development of every faculty with which he has been endowed.

The Krogh Gravel Mill.

From Mariposa to Siskiyou county, Cal., and extending into Oregon, there are extensive bodies of gravel which in their deep-seated or unoxidized portions are known to miners as "blue leads." Many of these ancient river beds or channels contain gold in quantities that pay good profits to work. These bodies of gravel are frequently more or less cemented. So firmly cemented are these gravels that the largest hydraulic giants under the heaviest pressure are unable to disintegrate them and separate the gold. Masses of cemented gravel will travel for miles in sluiceways without breaking up fine enough to release the gold. Gravel containing low values can be mined and worked at a profit if some comparatively inexpensive method is had for disintegrating the cement. These cemented gravels frequently carry high values in gold.

The accompanying cut illustrates a mill which is built to handle cemented gravels, and according to the manufacturers meets the requirements of working at low cost with high efficiency and large capacity. Several have been built and are in use, demonstrating their adaptability and success. A process of separation and not of crushing is employed, as a large per cent of the wash (the boulders constituting fully 60%) is dead material.

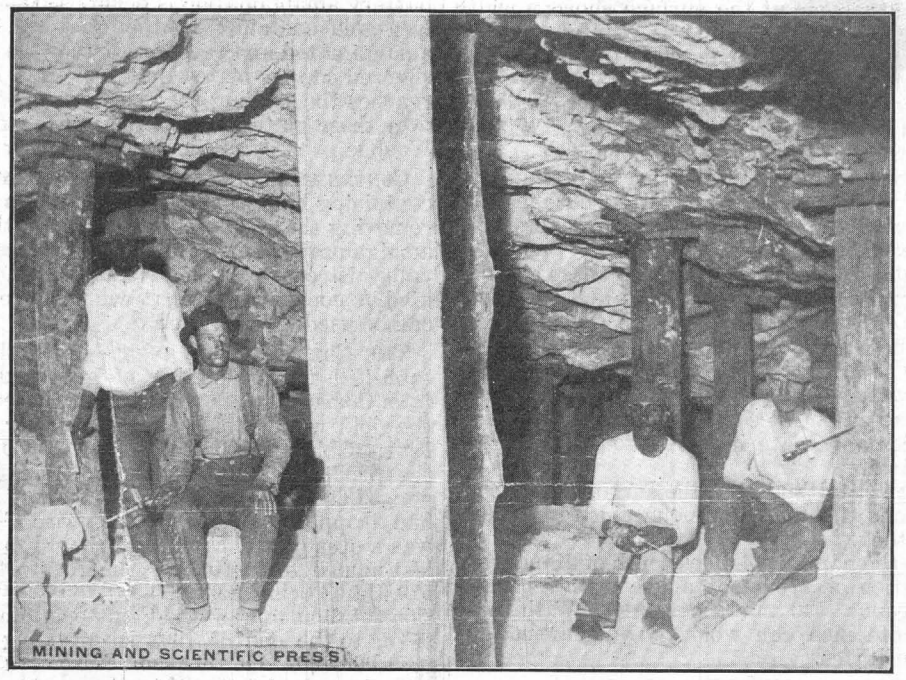


Krogh Cement Gravel Mill.

The Krogh gravel mill is designed to handle this material and to operate on the principle of disintegration, the boulders being employed to work against themselves, and by contact wear away and reduce to pulp the finer particles of gravel which adhere to them. The mill may be described as a revolving hexagonal barrel. By reference to the accompanying illustration it will be noted that the six sides consist of parallel bars or grizzlies, through which the material drops when reduced sufficiently fine, when it comes in contact with a screen, and if then fine enough drops through onto an amalgamating table. If not of the right consistency to pass the screen, it is returned to the revolving mass of material and ground still finer. The mill is about 6 feet long and 4 feet wide, with feed entrance at one end, and discharge for waste material at the other, the fine gold-bearing material passing out at the sides. The manufacturers say it has been shown under working test that one of these mills, weighing but thirteen tons, will readily disintegrate ten tons of cement gravel per hour, requiring 10 H. P. and revolving fourteen to twenty-four turns per minute. Further particulars regarding this mill can be obtained from the Krogh Manufacturing Co., 519 Market street, San Francisco, Cal.

Posts and Breasting Caps.

In mining in veins or beds some system of timbering is usually necessary, though in some dry regions large areas are stoped without the aid of timber supports. In limestone this is often, though not always, the case. Square sets are elaborate and expensive, and there are often instances where the more simple method of posts and breasting caps, or posts alone, may be safely employed to support a roof. The accompanying engraving illustrates a stope in a Cananea mine in Mexico, where the roof is firm enough to admit of this kind of timbering. In this instance a piece of 2-inch plank is placed above the post and a number of wedges driven in to make it firm. By carrying a line of these posts and caps sufficiently close to the face extensive stopes may be cut on flat veins. This method of timbering is commonly employed in drift gravel mines and in many coal mines. Often a great many of these "props" may be recovered when retreating from worked-out portions of the mine, the roof falling as the support is withdrawn. Whether it is economy or not to remove any particular post is a matter of judgment which the foreman or superintendent must decide. Often the labor expended in the removal of a post is worth more than the post itself when it has been recovered. This practice is much more common in coal than in metal mines.



Stope in a Cananea Mine, Mexico.

Mechanical vs. Hand Stoking.

A comparative test of hand stoking against mechanical feeding of pulverized coal dust, using the C. O. Bartlett & Snow system of burning pulverized coal, was made on Feb. 2, 1904, at the McCormick Division of the International Harvester Co., Chicago, Ill. The test was carried on under two B. & W. boilers, rated at 120 H. P. each, with a total heating surface on each boiler of 1200 square feet, the ratio of heating surface to grate surface being 44.4 to 1. The C. O. Bartlett & Snow Co. give the results of the test as follows: In hand stoking, 9400 pounds of fuel, Illinois coal screenings (10.5% moisture), were employed, and in the mechanical feeder 9713 pounds coal dust (40-screen) were used, containing 3.5% moisture. The screenings produced 1934 pounds of ash and refuse, the dust none at all, beside making practically no smoke. In the mechanically fed boiler 66,255 pounds of water were fed and in the other 43,193. Total water evaporated in the mechanically fed boiler, 64,940 pounds; in the hand-stoked, 42,329 pounds. With the former 253.9 H. P. were developed, being 55.5% efficiency, and with the latter 165.5 H. P., which is estimated at 41.53% B. T. U. The relative cost of the two methods is shown as follows:

COST OF EVAPORATION, $1.72 COAL PER TON.

Cost fuel per 2000 pounds of pulverized coal delivered in boiler room $2.10

Cost required to evaporate 1000 pounds of water from and at 212° F. (exclusive of firing, repairs, depreciation, etc.) 0.1455

$\frac{12,555}{965.8}$ = 13 pounds water evaporated (if total heat units were used) per pound coal as fired.

$\frac{7.214}{13}$ = 55.5% efficiency.

COST OF EVAPORATION BURNING SCREENED COAL.

Cost fuel per 2000 pounds of screened coal delivered in boiler room $1.72

Cost required to evaporate 1000 pounds of water from and at 212° F. (exclusive of firing, repairs, depreciation, etc.) 0.1770

$\frac{11,300}{965.8}$ = 11.7 pounds water evaporated (if all heat units were used) per pound of coal fired.

$\frac{4.859}{11.7}$ = 41.53% off.

The Deepest Shaft.

The Red Jacket shaft of the Calumet & Hecla copper mine, in northern Michigan, is the deepest in the world. It has taken nine years of day and night work to sink and has cost $2,500,000, says Industries and Iron. This shaft is vertical, but all of the other shafts of the Calumet & Hecla follow the dip of the lode. Work on it was started in 1889, immediately after the last of the three great underground fires in the older workings of the mine, which did damage of more than $1,000,000. Work has been continued upon it since that time, and the shaft stands without a parallel in mining. It is 4920 feet in depth, or 360 feet less than a mile. It contains six compartments, each equal in size to an ordinary mining shaft, four of which are used for hoisting rock and lowering timber. One shaft is utilized for the ladderways, and the sixth compartment carries the wires and pipes for telephones, light, power, water and compressed air.

Pyrite Smelting Without Coke.

Written for the MINING AND SCIENTIFIC PRESS by LEWIS T. WRIGHT.

From prehistoric time, copper has been extracted from cupriferous pyrite by a fire treatment consisting of alternate roasting and smelting with carbonaceous fuel and fluxes. Each roasting oxidized a portion of the sulphur and iron and each smelting removed, as iron slag from the copper sulphide, the iron oxidized in the previous roasting process; and these alternating operations were continued until a nearly pure copper sulphide was left; such copper sulphide by melting and oxidation finally became the refined metallic copper which was the aim of these combined processes. The treatment of the ore therefore was one of elimination, in stages, of sulphur and iron, and finally the sulphur; it was a gradual scraping away of the husk and chaff to find the valuable grain.

The successive oxidations and smeltings were carried on with the aid of carbonaceous fuel, which, by its reducing action, is counter-active to an oxidizing process.

Let us review for a moment the so-called English method of smelting cupriferous pyrite:

1. An ore (say 5%) is roasted in a reverberatory furnace with the aid of 15% its weight of coal.
2. The roasted ore is then smelted with the necessary flux, thereby cutting out, as slag, the iron oxidized in No. 1. This smelting is carried on with the aid of 40 to 45% coal and leaves a 35% copper matte or coarse metal.
3. The 35% matte is roasted in a reverberatory with the aid of 40 to 45% coal.
4. The partly oxidized 35% matte from No. 3 is now smelted with the aid of 50% coal, again cutting out, as slag, the iron previously ozidized; this leaves a 75% matte.
5. This 75% matte (white metal) is melted in a reverberatory furnace and by a succession of oxidations and reductions, in which the oxidations prevail, is now freed of its sulphur, leaving 'blister copper.' This is done with the aid of 60% coal.
6. The blister copper is refined by a succession of partial oxidations and reductions to fine copper.

The practice of large-scale copper smelting in the United States quickly resulted in the use of blast furnaces and converters, and by 1895 the old cumbersome, laborious and fuel-consuming method had been largely abandoned in favor of more rapid (and more economical) treatment. The coarse sulphide ore was often roasted in heaps with a little cord-wood and the fine ore was roasted in mechanical furnaces, especially if in the form of concentrate, with a not inconsiderable proportion of fuel. The smelting of the roasted ore in the blast-furnaces was effected with a quantity of coke equal to about 10% of the weight of the charge, producing a 40 to 45% matte, which was brought up to blister copper in the converters, without the expense of further fuel, except that required by the blowing engines. The sulphide fine, after roasting, was briquetted and smelted in blast-furnaces or smelted direct as a hot calcine in reverberatories. This last method offers advantages in localities where suitable fuel can be obtained at a low cost and where the ore is naturally fine.

At Keswick frequent attempts were made to smelt the sulphide ore (which was pyrite with some chalcopyrite), with hot blast but at first without increase of economy.

The coarse ore was, therefore, roasted in heaps or kilns and a smelting charge of the following average composition was made up for the water-jacket blast-furnaces:

Calcined ore	49 5%
Cupriferous pyrite	12.3%
Raw matte	8.1%
Slag	7.6%
Fluxes	22 5%
Coke	9.3% of total burden
Grade of matte produced	42.0%
Rate of running	5 49 tons per sq. ft. per 24 hr.
Blast	22 oz.

This charge at first ran with extreme difficulty, the furnaces chronically and promptly freezing up. The difficulty was wrongly attributed at the time to the presence of a small amount of zinc in the ore, and it was recommended by the metallurgist then directing the smelting operations to crush the ore, to roast it in mechanical furnaces and to smelt the product in reverberatory furnaces. An adoption of this recommendation would have entailed the reconstruction of the smelter.

When I took charge in the beginning of 1897, I discovered that the cause of the difficulty was due to the top of the charge being held too low in the shaft of the furnace and on carrying the charge a little higher the trouble immediately disappeared.

The normal charge was calcined ore only and the sulphide in the above average represents occasions when by especially good roasting of the coarse ore the grade ran up beyond that required, and sulphide ore was added to the charge to bring the matte down to the normal grade. In the reverse manner, if the coarse sulphide had not been so well roasted, the grade of matte fell below the normal and had to be re-treated; and thus raw matte appears in the average charge.

The furnaces ran with remarkable regularity and ease; but the heap roasting was an unsatisfactory feature. The fine sulphide had to be roasted in mechanical furnaces and briquetted. Occasionally, when the supply of calcined ore ran short, all-pyrite charges were run; but always with the production of a low-grade matte that required two or three re-smeltings to be brought to the normal grade, of 40 to 45%. No attempt was made at that time to reduce the coke on the pyrite charges and the operation was, therefore, not economical; it seemed that, owing to the inability to secure a reasonable concentration, the all-pyrite smelting could not become an economical practice. Later, the roasting of the coarse sulphide ore was entirely abandoned and the fine sulphide was roasted perfectly and a mixture of coarse sulphide (pyrite) and well roasted fine sulphide enabled a 40 to 45% matte to be produced economically.

Other attempts to run all-pyrite charges, this time again with the aid of hot blast, did not succeed, owing to the old difficulty of low concentration; and when the coke was reduced to about 3% the furnaces quickly closed up with obstinate accretions. The practice of running all-pyrite charges was abandoned at that time, chiefly owing to the unsatisfactory oxidation of the charge. Many mistakes, as afterward discovered, had been made in the make-up of the charge; among other evils, the furnaces were overloaded with slag.

The first attempt at all-pyrite smelting failed because it was not then realized that the coke then being used could be reduced and that, being counter-active to oxidation, its presence prevented the required concentration of the pyrite into high-grade matte. With 9 or 10% coke on a charge of pyrite, a 12 to 15% copper matte ran through the furnaces like water. Being intensely hot and liquid, the ganister and fire-brick lining was eaten away and the hot, low-grade matte was frequently bursting out from the furnaces, producing explosions. The amount of air in the blast was only sufficient for the combustion of the coke.

When the first serious attempts were made to run all-pyrite charges with hot blast, with only the amount of coke absolutely necessary to keep the matte and slag running, a charge was made up, of which the following are two examples:

Cupriferous pyrite	58.7%	60.0%
Raw matte	4.3%	3.2%
Fluxes	16.6%	10.0%
Slag	20.4%	26 8%
Coke in charge	2 0%	3.5%
Copper in matte	18.7%	18 7%

The runs were of short duration because in from 5 to 10 days the obstinate accretions threatened to close up the throat of the furnace entirely and, to prevent a freeze up, the charge was modified.

It must be admitted frankly that the above-mentioned attempts at all-pyrite smelting were purely empirical and in no sense founded upon scientific reasoning. Had the experiments been varied as regards the proportion of inert heat-absorbing slag, reducing this to a minimum, no doubt it would have been then and there demonstrated that such charges would run entirely without coke and the concentration would thereby have been somewhat better. But those were not our scientific days of pyrite smelting.

However, the advantage of hot blast in the case of a composite charge of coarse sulphide and well-calcined fines was abundantly proved, and hot blast was adopted for all the furnaces. It was immediately seen that the hot blast, other conditions being equal, enabled the furnaces to run one-fifth faster with the use of one-fourth less coke and produced 25% higher grade matte. This was the result of being able to take off from the charge so much de-oxidizing carbon.

The composite charge of sulphide and well-roasted fines was then smelted with hot blast in a two-stage process. The first-stage furnaces carried the following average charge:

Calcined ore	26.1%
Cupriferous pyrite	35.5%
Flue dust	9.7%
Slag	14.5%
Fluxes	14.2%
Coke in charge	4 % of total burden
Copper in matte	31 %

This matte was re-smelted with some sulphide and calcined fine ore in a charge, of which the following is typical:

Calcined ore	31.4%
Cupriferous pyrite	8 7%
Raw matte	26 7%
Slag	13.3%
Flux	19.9%
Coke in charge	5.3% of total burden
Copper in matte	53.5%

The final average charge of all the furnaces, both first and second stage, was now:

Calcined ore	28.8%
Cupriferous pyrite	24.9%
Raw matte and flue dust	14.7%
Fluxes	17.3%
Slag	14.3%
Coke in charge	5 2% of total burden
Copper in matte	53.5%
Rate of running	8 tons per sq. ft. of furnace area per 24 hr
Blast	28½ oz

It will be seen that a notable economy of coke had resulted. The make-up of the charge on all furnaces was one that produced the smoothest running. Long campaigns were the rule. The rate of driving had increased. This was partly due to the increased blast pressure and partly to its increased temperature.

During the attainment of these results I had been endeavoring to secure some information respecting the necessary and minimum heat requirements of a copper-smelting furnace, and to ascertain the minimum amount of pyrite that must be oxidized in a given time in such furnace to furnish the heat requirements. It was evident that the amount of air required was necessarily more than that which we are in the habit of calling the 'theoretical,' meaning that which would be required to furnish the amount of oxygen indicated by the equation FeS_2 plus 5O equals FeO plus $2SO_2$, because thatre-action would cease when the tension of the SO_2 reached a degree much inferior to that indicated by the equation. Finally I became convinced that the calorific value of pyrite as a fuel was sufficient for its self-smelting; again, I made attempts to run pyrite charges without carbon fuel, but invariably failed, because of the incredulity of my staff, who were firmly convinced from past failures that it was impossible.

Finally, to convince those operating the furnaces and to induce them to effect the required result of their own volition, it was decided to order it to be done and forbid the use of any coke in the charge except that needed for starting the furnace, it being understood that if the furnaces froze up the general manager would hold himself responsible, and that the crew could have the fun of digging them out.

As a result it was quickly demonstrated that pyrite *could* be smelted without coke and monthly furnace runs with an average consumption frequently of only 0.1% coke and lower, which coke was only required to start the furnace, became the practice with a charge made up as follows:

Cupriferous pyrite	74 3%
Flue dust	9.0%
Slag	2.8%
Fluxes	13.9%
Coke in charge	0.32% of total burden.
Copper in matte	26.8%
Rate of running	8.75 tons per sq. ft. furnace area.

If it had been then convenient to convert this grade of matte direct to blister copper, the smelting might have easily stopped there. The matte resulting from this charge was, however, all re-smelted in a charge of the following composition:

Calcined ore	8.8%
Raw matte	19.4%
Cupriferous pyrite	31.1%
Flue dust	6 4%
Slag	18.4%
Fluxes	15.9%
Coke in charge	4.3% of total burden.
Copper in matte	41 8%

The average of all furnaces was:

Calcined ore	4.3%
Cupriferous pyrite	51.5%
Raw matte	10.6%
Flue dust	6.3%
Slag	11.9%
Fluxes	15.4%
Coke in charge	2.7% of total burden.
Copper in matte	42 0%
Rate of running	8.83 tons per sq. ft. furnace area.
Blast	32.2 oz.

The smelting of pyrite to 27% matte had therefore been finally carried out in blast furnaces on a large scale without the aid of coke. So far, attempts to carry it along, without the use of heated blast, have failed. It will be noted that the furnaces run very fast; that is apparently one of the conditions of success. The amount of fuel used in heating the blast is equal to about 1 to 1¼% coke.

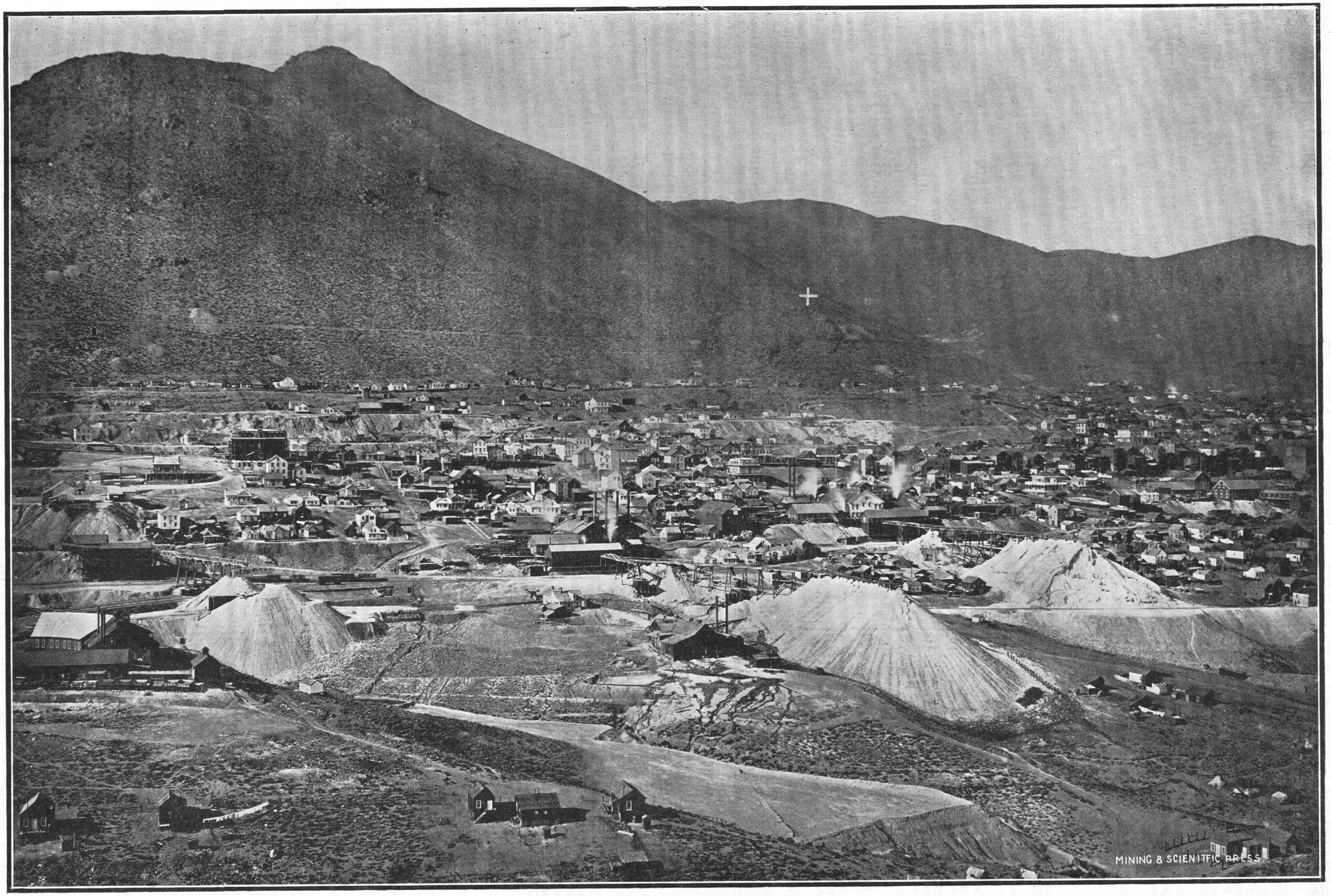
It now having been fully demonstrated that the furnaces would run without coke with a sulphide charge of the right composition, efforts were made to force the concentration so as to produce a 35% matte in the first stage and to convert this to blister copper direct without the intervention of a second smelting stage, and to smelt the fine sulphide direct without preliminary calcination and bricking, which latter process is very expensive.

This object was achieved, but the one and only smelting stage had then to clean all the converter slags and work up all the fine sulphide ore, the flue-dust and the furnace cleanings; therefore the average furnace charge of sulphide ore became somewhat diluted to:

Cupriferous pyrite, including fine	65.6%
Flue dust	8.0%
Slag and furnace cleanings	12.1%
Fluxes	14.3%
Coke in charge	1.8% of total burden.
Copper in matte	33.7%
Rate of running	8.75% tons per sq. ft. of furnace area.

Though the furnaces would often run without coke, the slightly heavier burden of inert material and lessened amount of sulphide ore on the charge seems to necessitate the occasional use of a trifling amount of coke. However, the operation, being reduced to one stage of smelting, is much simplified, and the lower grade of the matte adds but little to the cost of the converting department, and there is the advantage that the whole of the slag is discarded at the lowest tenor of copper, and that the whole of the fine sulphide ore is smelted without previous calcination and bricking.

The two great difficulties in the practice of pyrite smelting are the obstinate and rapidly forming accretions, tending to close up the furnace, and the low-



THE COMSTOCK IN 1876.

Virginia City, with Mt. Davidson in the Background. Chollar, Hale & Norcross, and Savage Mines in the Foreground.

The Comstock in 1876.

Never since the world began have larger or more valuable orebodies been discovered than were uncovered in the Comstock lode between 1870 and 1876. There have been many great mines in many lands, but none have yet eclipsed what was actually discovered and exhausted on the Comstock. The history of the great lode teems with exciting incidents and romance; Arabian Nights' tales are not more entertaining nor less wonderful than the story of the heroic work accomplished by those modern genii—the Comstock miners.

The lode was discovered, almost simultaneously, at two different points, one at Gold Hill, the other a mile and a half farther north at the Ophir mine. After nearly ten years of somewhat desultory placer mining in Six-mile canyon and Gold canyon, gulches heading at Virginia City and Gold Hill, respectively, the lode itself, which was the source of the placer gold, was uncovered. At the present time the discovery would have been made within a week. At Gold Hill the quartz croppings, soft and crumbling and iron-stained, carried mostly gold, with comparatively little silver, near the surface. This, beyond doubt, would in time have attracted sufficient attention to have eventually given the Comstock the fame it has since enjoyed, but it was the discovery of McLaughlin and Reilly, of the black silver sulphide in the Ophir croppings, that was the immediate cause of the rush to Washoe. These inexperienced miners followed up a poor pay-streak, making barely a living on the steep slope of Sun peak, now called Mount Davidson. Water was very scarce, and to secure sufficient to wash their dirt in a rocker, they dug a small pit where there was a trickling spring, or rather seepage, of water. When this little basin was about four feet deep they encountered a black, granulated, heavy mineral, and, miner-like, panned a shovelful to satisfy their curiosity. The pan of black dirt was washed with difficulty, owing to its high specific gravity, but it yielded, when the black stuff had been dexterously removed, a handful of yellowish-white metal, which they were slow to realize was nearly all gold.

As they stood gazing on this prospect, and speculating on its value, Comstock put in an appearance, astride a small broncho. He caught the glint of metal in the pan, and in a moment was off his horse examining the pannings, and scratching the dirt in the pit with his fingers. Comstock was a man of quick wit and prompt action, though of no education. He realized that something unusual, and possibly of great value, had been discovered. Gazing earnestly at the miners, Comstock gravely informed them that they were working on his ranch. He claimed to have located a farm of 160 acres on that rocky mountainside, where the only verdure was a scattering of stunted sage brush, where there was no water, and but scanty thin soil. It is more than probable that the prospectors failed to realize the value of their find, or they would not have so meekly permitted Mr. Comstock to impose upon them as he did. He was given a large interest in the claim, and an additional claim was staked for his partner, Emanuel Penrod. Comstock talked loud and much about his mine, and in time it became to be known as Comstock's mine, and later, as its magnitude began to be realized, it was called Comstock's lode, and eventually the Comstock lode.

In a few weeks it was learned that the black, heavy sand that had been considered such a nuisance, and had been thrown away, was silver sulphide. The discovery was made through a sample sent to Nevada City, California. Within a day men left on horseback, in wagons, and on foot for Washoe, as the district was called. No small wonder—they were anxious to reach a camp where the miners threw away ore worth from $3,000 to $10,000 per ton.

There are few parallels in the history of mining equalling this rush to Washoe. The stampede to the Kimberley diamond field in South Africa resembled it greatly, but the more recent mining excitements dwindle into insignificance in comparison with either. A city sprang into sudden, though rude, existence on this barren, rocky hillslope in an incredibly short time. It was many miles from any other city; everything had to be freighted into the region over rough mountain roads—food, clothing, and materials of every kind. More than 6,000 ft. above the sea, the wind-swept town of tents, boards, gunnysacks, and old tin cans, presented a strange sight, and was a picture which could not be appreciated if not seen.

Thousands of eager, excited men thronged the streets, the public houses and the hovels, which latter afforded them but little shelter from the weather. Notwithstanding the numerous drawbacks, the camp grew quickly into a flourishing city of 30,000 people, while outlying districts held several thousand more. Theaters, large merchandising establishments, churches, schools, beautiful homes and public buildings sprang up as from the very ground. The hotels were elaborate and were furnished like palaces, the workmen lived and dressed like nabobs, and all went well in those days at Virginia City. For more than ten years the mines of the Comstock lode produced famously. Such orebodies had rarely, if ever, been seen before. Millions upon millions in gold and silver came from those great storehouses of wealth. Some idea of the cause of all this turmoil and frenzy of men may be gained from a statement of production from some of the most noted of the bonanzas. The figures are approximate: In the Gold Hill district the Yellow Jacket produced $25,000,000. Joe Bowers, a claim 20 ft. long, produced several millions, and this claim was afterward consolidated with the Imperial and produced several millions more; Belcher, $40,000,000, this from below 1,000 ft. from the surface; Crown Point, $30,000,000, and others, large amounts. In the Virginia City section, Ophir and Mexican produced about $25,000,000; Gould & Curry, $15,000,000; Savage, $17,000,000; Hale & Norcross, $10,000,000, and Chollar, $13,000,000. Other millions were taken from other mines in the north and central portions of the great lode. Is it any wonder that men and women became frantic in their endeavors to win a fortune while the opportunity was passing?

And yet, the greatest and richest orebodies in this wonderful lode had not been discovered, and their existence was scarcely more than suspected, and that by only a few of the keenest observers. One of these was C. A. Luckhardt. After describing what was known as the South Ophir orebody, he wrote in 1868: "The ground south of this orebody for over 1,300 ft., including south portions of the California Company, Central No. 2, Kinney, White & Murphy, Sides and Best & Belcher, has been lying idle for years. It was explored to various depths, from 100 to 500 ft. below the surface, but never with any system; and nothing can be said of its value. It is very probable that much ore exists there, but it has not yet been laid open to view. A shaft, now 300 ft. deep, is being sunk with the object of thoroughly investigating the ground for ore." The ground here described by Mr. Luckhardt covered the great bonanzas of the Consolidated Virginia and California mines, which a few years later surprised the whole world with their vast output of gold and silver.

It is impossible here to describe the legal complications over these mines, the physical conflicts of the miners with scalding water or caving ground, and the unusual engineering problems of many kinds. But mention must be made, though briefly, of the invention of the square-set method of timbering, which was evolved on this lode in the Ophir mine by Philip Deidesheimer, who was employed by the Ophir Co. to devise some means by which they might in safety extract their ore. For the first 60 or 70 ft. the vein was small, and rich, and offered no unusual obstacle to mining by ordinary methods, but at 175 ft. the vein had widened to a mass of crumbling quartz and silver sulphide 65 ft. wide. The miners had exhausted every resource; they had spliced long timbers together, and were endeavoring to stope the ground, but it was found impossible longer to continue this dangerous method. Mr. Deidesheimer visited the Ophir mine and inspected the workings. It was evident at once to him that the orebody could not be extracted by methods commonly practiced Pillars were impossible, as the ore was too soft and crumbling to sustain their own weight. He determined to drive a crosscut from wall to wall. This was done, and the cutting was timbered with posts and caps, but the caps, instead of crossing the opening from side to side, were laid on a line normal to the strike of the vein, thus forming on both sides a continuous line of caps from foot to hanging. Having successfully accomplished this, a second crosscut was cut by the side of the first, and a third line of posts and caps was set up in like manner. The sets were spragged with pieces of 2 in. by 4 in. scantling, but it soon became evident that something more substantial was required; accordingly, the 2 by 4-in. sprags were replaced by 'ties' of the same dimensions as the posts and caps, but as the caps, which met on top of the posts, occupied all of the space on the posts, the ties were supported by iron lugs driven into the posts at a proper height. A raise was now made near the center of the vein, where the ore was particularly rich. As soon as the excavation was sufficiently large, posts and caps were required. As the posts, if set flush upon the caps of the first set, would be insecure, mortises were cut in the caps after they were in place, and the posts were provided with tenons to fit into them. A few sets were inserted in this manner, when it was concluded to frame the timbers so that when in place a mortise would be formed at the point of their union. When this had been done, the square set, which has made possible the safe removal of an orebody of any size, was practically complete. The sills, butt-caps, angle-braces, and other parts of the square-set system as now known, came later, the entire system being evolved as the necessities of the case required.

It is of interest to know that the first engine on the Comstock lode was erected at the Ophir mine. It was rated at 15 h. p. and was used to run a small pump. It forms an interesting contrast to the magnificent installations which have since been built on the lode.

There is a well-founded report that early in the 70's, while James G. Fair was superintendent of the Savage mine, he had a drift run westerly from the 1,000-ft. level of that mine into the foot-wall country, and thence by a circuitous route through the Gould & Curry and Best & Belcher mines into the Consolidated Virginia—the ground described by Mr. Luckhardt as possessing great possibilities. Here the crooked drift encountered promising indications and then good ore. Unexpectedly the order was given to abandon the drift, to draw the timbers and allow it to cave, ostensibly because it was too poor to mine. The four men, Mackay, Fair, Flood and O'Brien, who afterward became the most noted of all the notable men on the Comstock, had already formed their famous coalition; quietly they began to buy up the shares of the Consolidated Virginia and California mines, a procedure requiring not only abundant money, but much shrewdness and finesse. It has been stated that the control of these mines cost the firm about $50,000, and control usually meant complete ownership in those days. When they had secured the management of the coveted mines, which required nearly two years, they attacked the problem of their development with vigor. The old Consolidated Virginia shaft was sunk as rapidly as skill and money could drive it, and simultaneously a drift was started from the Bonner shaft of the Gould & Curry, at the 1,167-ft. level, and was driven with all speed through that ground into, and through, the Best & Belcher, and into the Con. Virginia, where about 150 ft. from the line a small vein of ore was encountered. The drift was continued, and in 30 ft. the seam had widened to seven feet of high-grade ore. Further exploration proved the vein to continue and to grow both larger and richer. The shaft also penetrated the same orebody. Levels were run and sinking continued. More, and constantly more, ore was brought to light, and as level after level was run and the orebody blocked out, it began to look as if there would be no limit to the size and value of this phenomenal mass of silver-gold rock.

For more than two years the development of this, the greatest orebody in the world, continued. Millions of dollars had already been taken from it, and unknown millions remained. On one level this great mass of ore was over 350 ft. wide. It was several hundred feet high, and more than 1,000 ft. long. From it was extracted, by official report, by the first milling, over $130,000,000. This was the 'Big Bonanza.' Later another orebody, known as the Little Bonanza, was found near the first, from which $25,000,000 was taken. Over 1,400,000 tons of tailing, up to 1882, were worked over three times, and some of them are being again worked for the fourth time, now with the cyanide process, by Charles Butters.

In 1875 Virginia City had grown to a substantial town, with many handsome buildings, but it did not escape the fate of most other mountain mining towns, and on October 25, 1875, a fire swept the greater portion of the city out of existence. With it went many of the elaborate hoisting and milling plants.

The illustration on the opposite page is from a photograph of the central portion of Virginia City taken about one year after the great fire. It shows a better, larger and more substantially built city than that which was burned—a tribute to the enterprise and energy of its citizens.

Several of the more prominent buildings can be seen. The nearer mines are the Hale & Norcross, Savage, and Chollar. The white cross on the mountainside is 'Point A,' the datum to which all important measurements on the Comstock have been referred. The gulch to the right of the cross is Spanish ravine. It was just this side of the ravine where the uppermost houses are seen that the Ophir discovery was made. The Consolidated Virginia and California mines are just beyond the limits of the picture on the right.

RADIO-ACTIVITY.—It is a fact that the fluorescent effects of the Rontgen rays incited Becquerel to his examination of uranium, and led to his discovery of its radio-active properties; and from this to the isolation of radium by M. and Mme. Curie, and to the splendid series of researches which have been carried out on that substance and on other allied substances, the way is clear. Rontgen's discovery was made only 10 years ago, and it is a marvelous illustration of the large sum of human effort applied to the study of science, and of the active, one might almost say the radical, tendency of the modern mind, and in so short a time we have obtained so great a body of established knowledge, and experienced so complete a revolution in our most fundamental modes of scientific thought.—*Science.*

THE COMSTOCK.—Our illustration of Virginia City is borrowed from a set of magnificent photographs of the Comstock, taken in those early days by the noted old landscape photographer, C. E. Watkins, whose beautiful pictures of Yosemite, the Big Trees, and other famous scenic points on the Pacific Coast have attracted world-wide attention. These Comstock pictures are what were known as silver prints. They are deep in tone, rich, and clear. The famous photographer, now grown old and deprived of his eyesight, lives in seclusion and poverty in San Francisco. Recently he had made for Clarence Mackay, at the latter's order, a set of handsome photographs on glass, showing the great works of Virginia City and many characteristic scenes on the Comstock when it was in the height of its glory. Copies of these photographs may be had by those who desire this pleasant reminder of the early days.

to gain the best results possible for their respective companies, they are familiar with all the latest mining machinery and are constantly on the lookout for some contrivance that will cut down operating expenses, they all, or nearly all, have tried the electric drill—with what result? You go to the machine shops and in the corner, where the scrap heap is, you find electric drills of every make and kind. These representative men of the mining profession have discarded the electric-drill. Could the air-drill ask more as a recommendation?

I do not want the electric-drill people to think that I am a knocker at heart, for I am not; I believe that some day the electric-drill will be made a practical machine for underground work, and when that time comes, I shall be one of the first to acknowledge it. We all admit the saving of power of the electric-drill over the air-drill—we cannot get around that fact—and we all want to operate as cheaply as possible. but in the air-drill we have a machine we can depend upon to do our work under any and all conditions and still put up with much abuse from the miner; the electric drill will not do that.

A word about these competitive tests. They are in most cases positively worthless; they are made for a shift or two in a rock that is advantageous to one drill or the other (intentionally or otherwise) and the drill which has shown its supposed superiority advertises a great victory. There is but one way to conduct such a test: take the two machines in question and put them together or in opposite shifts in a drift (shaft, raise or stope) for a week or two, then change them to another part of the mine in different rock or ore. During these periods keep careful account of all repairs, break-downs, amount drilled and all interesting data, sum it all up at the end of the test and decide which you want to buy. The drill that does the best work in one mine or district will fall below the standard in another mine or district.

I have confined myself to drills in this letter, for the reason that Mr. Rix has dealt with compressed-air machinery in general; I believe that this subject of drills is one of great importance, as there is so much money being expended by mine operators in experimenting in this direction. I hope both Mr. Hulbert and Mr. Rix will deal with the subject again, giving figures and data for us to think over and compare with our own figures. As you, Mr. Editor, state in your note at the end of Mr. Hulbert's article of Jan. 27, unless figures are accompanied by all the conditions under which the tests are made, they do not mean anything.

H. R. PLATE.

Denver, February 15, 1906.

Manufacture of Plaster of Paris.

The gypsum rock is reduced by a jaw crusher (cost, $1,000) to about one-inch cube. As this material is mined in large cakes, the opening must not be less than 20 by 12 inches. When crushed, the rock is dried in a rotary direct-heat dryer (cost, about $2,500). The products of combustion used in drying this material should not pass through the material on account of the danger of coloring it, that is, the drying must be done on the outside of the dryer, only. The size of the dryer will depend upon the capacity required; it should connect with a chamber to settle the dust, which is valuable. After the gypsum is thoroughly dried, it is again thoroughly crushed on an ordinary pot or bowl-crusher (cost, $300). It should then be ground to about 80-mesh. French buhr-stones are generally used (four of these, at $300 each). The ground gypsum is then passed into a calcining kettle (cost, $1,200 each), usually 8 ft. diam. and 8 ft. high, with gears, flues, fire-front, grates and doors, also with upright shaft and stirrers near the bottom, driven with heavy gears above. The ground material is slowly passed into the calcining kettle, which soon begins to boil. More material is gradually added, until the kettle is full. From the gypsum rock that has been crushed and dried thoroughly, a portion can be calcined within about one and one-half hours, the time depending upon the dryness of the gypsum and the quality of the finished product. The material contains enough moisture to boil it thoroughly for a short time, after it comes to a dead state; then it will boil a second time, and in many cases even a third time; the more it boils the quicker it will set. For ordinary plaster work only one boiling is required, but for fine work or plaster of paris two boilings are necessary. This calcining kettle is where the mechanical change takes place. After it is sufficiently calcined or boiled, as it were, it should be immediately emptied and placed in hoppers or bins made of iron or brick, after which it is ready to be conveyed and elevated to storage bins, from which it is packed into sacks or barrels ready for the market. As soon as the kettle is emptied, another charge should be immediately put in.

To manufacture, say, 100 tons of plaster per day, it will require the machinery mentioned above, with the addition of the necessary hoppers, bins, conveyors, elevators and the power. If it be desired to make this material into wall plaster, it will be necessary to add further one sand dryer and a hair picker; also the necessary apparatus for mixing the different materials.

The Price of Copper.

During the past few months the high level of prices for copper was not reached without some manipulation; but it must be admitted that the condition of the market—especially the statistical situation—fully justified an extremely high level of prices. The fact was that, according to the best information obtainable in the trade, surplus copper supplies in this country were actually wiped out, and the urgent demand on the part of home consumers forced the sellers to put up their prices for their home production. Of course, the wild stories which were circulated, as to the possibility of a 21 or 22-cent price, had the effect of inducing some consumers to 'overbuy' for forward delivery; but this did not occur until very late in the period of advances, and was probably mostly done by such consumers who had hesitated to buy at much lower prices. A glance at the statistical situation will show the justification for the high price of copper up to the end of 1905:

	Pounds.
The exports of copper during the first six months of last year amounted, in round figures, to	280,000,000
The total available supplies from production and imports for the whole year are estimated at	1,100,000,000
Or for the first six months, assuming the same ratio	555,000,000
Deducting exports	280,000,000
There remains available for home consumption	275,000,000

According to conservative estimates, consumption in this country probably absorbed 50,000,000 lb. per month, and it is evident that, if consumption during the first six months of 1905 absorbed such an amount of copper, the available supplies had to be drawn upon. Consequently, when the home demand—with a general revival of business in the steel and iron trade about the middle of last year—commenced to improve, and purchases were made for forward delivery, the market was found to be bare of stocks and easily advanced to 19 cents or thereabout.

Production is increasing, and a conservative estimate will put the figures for 1905, including the increased imports from Mexico and Canada, at 1,250,000,000 to 1,300,000,000 lb.—say at the rate of about 105,000,000 lb. per month. Exports have fallen off. China, which took during the last year 80,000,000 lb. of our export copper, is re-shipping part of the copper which the Chinese speculators had bought for the different mints to Europe. The total exports of copper for the past year, according to the official statistics, amount to 534,907,619 lb., of which about 80,000,000 went to China, leaving for Europe about 455,000,000 lb., as against European takings in 1904 of 555,000,000.

The effect of the high prices on European purchases was immediately apparent during the year 1905. Exports to Europe continued large during the first part of 1905—that is, as long as European purchasers were receiving copper which they had purchased at low prices during the latter part of 1904; but exports fell off during the latter part of the year and are now at rather a low ebb. They were about 15,000 tons, or 33,000,000 lb., during January, and are not likely to be very large during February and March. With the increased production, this will leave available for home consumption from 65,000,000 to 70,000,000 lb. of copper. It seems quite reasonable to suppose that, as long as the iron business continues as good as it has been, domestic consumers will absorb most, if not all, of the surplus left over after exports have been deducted from the production, although, as stated at the beginning of this letter, some consumers may have bought a little bit more copper than they actually need at present and may be willing to carry it over until later months.

At the present time there is a good deal of controversy and question as to the correct price of copper. The big producers in this country, probably controlling 75 per cent of the total production, have not changed their prices from the top level reached—that is, 18½ to 18¾ cents for Lake and 18⅜ to 18½ for electrolytic. But copper re-shipped from China has been pressed on the European market, and has been sold far below these prices. This has, naturally, tended to demoralize the domestic market, because the European consumers who are expected to supply themselves for the bulk of their copper in America have been able to cover their wants to better advantage by purchases of American copper re-shipped from China.

As with any staple article, so with copper, a small surplus creates the price for the bulk, and, therefore, at present the price is being called 17¾ to 18 cents, although the most influential producers do not dream of considering a sale at such a price for the time being, and are not likely to for quite some time to come. Consumers are in a waiting attitude, being comfortable for the next few months and seeing no inducement to provide for their future wants very far ahead, at present high prices. The results of such 'waiting contests' between consumer and producer have, as a rule, been disastrous for the producer, except in periods when the markets were artificially supported. If the copper market will continue in its present dullness for another month or two, there is always the possibility of one of the big producers changing his mind and cutting prices in order to accomplish sales, and, if this be done, it is doubtful whether other producers will have the courage of their convictions to hold and accumulate, for the time being, copper at the high level. The fact should not be lost sight of that for quite some time to come the bulk of the copper produced will be needed for home consumption and export, and accumulation of surplus stock will not be any burden to anybody, owing to the fact that surplus stocks were practically exhausted by the end of last year. There is probably no other staple article with as small surplus supplies as copper. The situation in this respect is so serious that in case of a serious accident, or the shut-down of a large producing mine, like the Calumet & Hecla or the Anaconda, for a period of a few months, an actual famine of copper would be possible, if business continues at the present rate.

All experts agree that copper prices in the long run cannot be maintained at the present level, but they do not agree as to the near future of the market. Some of them—and not the least shrewd—confidently expect a continuation of the present price level, as long as business conditions in this country continue as prosperous as they have been for the last three to six months.—X. in New York *Evening Post.*

COPPER COINS IN CHINA.—The enormous increase in the importation of copper into China recently is due to its unrestricted coinage into one-cent pieces and cash, which operation is virtually under the absolute control of the provincial authorities. While the multiplicity of mints threatens the debasement of the currency of the Empire, the central government leaves the question of production entirely to the viceroys of the provinces. As these officials realize a comfortable margin of profit on the coinage, there is no likelihood of its early cessation, and the extensive copper importation will continue. The Shanghai Chamber of Commerce has investigated this question and has informed the diplomatic corps at Peking that representations looking to the regulation of currency should be made to the government. The chamber pointed out that as the Chinese provincial governments imagine they have a perennial source of income from the profits of the mints, they may fail to grasp the dangers of depreciation because of over-issue. It was further suggested that if restrictions be not established, foreign trade in China must inevitably suffer. In the report of the trade of China and abstract of statistics it is estimated that the output for 1904 approximated 1,745,000,000 of copper pieces and the chamber of commerce declares that by 1906, when all the mints, new and old, are in operation the output will reach in round numbers 16,413,000,000 pieces. There are 18 or 19 mints now in operation in China, but although bankers and merchants have given the subject close study, they find it extremely difficult to obtain through unofficial channels absolutely accurate information as to the present producing power of the various mints established. These conditions indicate a growing demand in China, and it is estimated that the United States now exports to this country practically one-half of all the copper that is used. The American 99.6 electrolytic copper is popular because it can be worked to advantage in the mints, and as their purchases about cover the entire importation it is apparent that the only way to increase the demand for American copper is to decrease the price. Australian copper, sold through British and German syndicates and metal exchanges, is also largely represented on this market. The importation of copper disks or blanks, the same size as the coins themselves, has been prohibited by the Chinese Government for the reason that individuals brought them in and, by using a home-made stamp, more or less crude, but nevertheless effective, established a lucrative industry. These coins circulated freely in the interior, and the authorities found it essential to suppress the competition. The customs authorities will, however, admit copper disks through the custom-house for delivery to government mints on an order from Peking. Such disks are now made in England, Germany, and Japan, and are said to be more profitable for export than ingots. There is also a demand for copper strips 2½ to 3 in. wide, of the same thickness as the coin. These strips are stamped at the mints and placed in circulation, saving time and decreasing somewhat the expense of coinage. In view of the enormous demand for copper, which it seems probable will continue for several years unless unexpected restrictions on coinage should be imposed, it would appear advisable for American copper men more carefully to investigate the conditions than they perhaps have up to the present time. This information can be obtained either through trusted representatives in China or by sending out an expert, and it is believed that the results would justify the outlay in time and expense.

TIMBER PRESERVATION.—Wood, for structural use, should be cut when the sap is down, that is, in winter. If cut at this season and placed under water, it lasts well. The Poughkeepsie railroad bridge, over the Hudson river, has stone piers that stand on 12 by 12 timbers set on cribbing, all the timber-work being under water and thereby preserved. In the tropics, timber should be cut when the moon is down; if cut at full moon, or when that luminary is rising, the timber will rot in six weeks. This is a fact, for which no explanation is as yet forthcoming.