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Copper mining at Cananea, Sonora, Mexico

Albert Hill Fay

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COPPER MINING AT CANAHEA
Sonora, Mexico.

BY
ALBERT HILL FAY

A THESIS FOR THE DEGREE—ENGINEER OF MINES
COPPER MINING AT CANANEIA, SONORA, MEXICO.

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COPPER MINING AT CANANEA,
Sonora, Mex.

Fifty miles southwest of Bisbee, Arizona, is one of the largest copper mines in the world, a mine which six years ago was in the throes of the prospecting, developing, and litigation periods, and now turning out over five million pounds of copper bullion per month. This property is located at Cananea, District of Arizpe, Sonora, Mexico, and is owned and controlled by the Cananea Consolidated Copper Co. S.A. It is situated upon the northeast slope of a short range of mountains from which the town of Cananea derives its name. The port of entry for this part of Mexico is Naco, Arizona, from whence a standard gage railroad wends its way around the south side of the San José mountains, and then across a broad north-south valley some thirty miles wide. In the center of this valley is a small ridge (forming a water-shed) which extends east and west, near the center of which rises the San Pedro river, which flows to the north and finally reaches the Gulf of Lower California via the Gila and Colorado rivers in Arizona. From this same water-shed, but to the southwest, flows the Sonora River, whose waters are lost in the desert sands southwest of Hermosillo.

If this water ever reaches the ocean, it is through some underground currents.

The topography of this section of the country is that of an arid, rolling waste of land, studded here and there with small groups of mountains, each covering an area of five to fifteen miles in diameter. These groups are ten to thirty miles apart, and attain an altitude of three thousand to five thousand feet above the surrounding plains. Such a group is the Cananea range. Thirty five miles north, in Arizona, are the Huachuca mountains; twenty five miles east are the Sierra de Ajo mountains;
twenty five miles northeast are the San Jose mountains, and twenty five miles further to the northeast are the Mule mountains, made famous by the enormous copper deposits at Bisbee. The Manzanel mountains are fifteen miles to the southeast of Cananea. On the west side of the Cananea range the mountain groups are more numerous and the valleys correspondingly less in size. These various groups are quite rugged, owing to the great amount of erosion that has taken place. Many of them show the effects of volcanic action. According to Mr. W. H. Weed, and also Mr. R. T. Hill, the central part of the Cananea group is the neck of an ancient volcano, and the slopes of the foot-hills are covered with great depths of volcanic ejecta. The broad valley to the east is covered with a vast sedimentary deposit, many hundreds of feet deep. This has been proven by a well drill which was sunk fourteen hundred feet near the San Pedro river, on the railroad right-of-way.

The town of Cananea consists of some five or six villages (one at each of the mines, and one each at the Concentrator and smelter, and has an estimated population of 9000 to 12000, of which about 3000 are Americans, 5000 Mexicans and several hundred Chinamen. Like the majority of other large mining companies, this company has a large merchandise establishment, but the employees are not compelled to make their purchases there. They also operate a banking institution, and have a well-equipped hospital. A Y.M.C.A. building has been provided for the free use of the employees, and there, will be found a large number of daily papers, magazines and writing material. There are two church buildings, one Protestant and the other Catholic. One weekly news paper (Cananea Herald) is published here. For those who are socially inclined, recreation and amusement can be obtained at the Cananea Club, which has a membership of about 150.
Timber and water.—When these mines were first opened six years ago there was a large amount of pine timber suitable for use in the mines, but the devastation caused by two or three saw-mills has culled out all the best timber near the mines, so that now, all that is left is scrub oak suitable only for fire wood, and even this is becoming scarce near the works, and sells at $15.00 Mex. per cord that will measure about three-fourths of a standard United States cord. The Mexicans have learned how to increase the amount of wood in a given tree, they simply cut it three feet long instead of four. Of course this does not give more wood, but it does very materially increase the number of cords. The wood is ***cut on the mountains and carried on burros to a place where it can be loaded on a wagon, or if near the Narrow Gage railroad, it is piled at the track and brought in by rail. Native timber obtained at a distance of five to seven miles still furnishes lagging for the mines.

There is scarcely any spring water in this group of mountains that reaches the surface, consequently all the canyons and gulches are dry except during the rainy season,—July and August. The Cobre Grande Mine at a depth of 200 ft. was the first one to develop water in quantity, yet as compared with the amount of water from other mines in various localities, the amount was comparatively small. This shaft has been sunk to a depth of 380 ft., and a pump installed, which furnishes part of the water for use at the furnaces. The main supply, however, comes from Ojo de Agua, nine miles east of town at the head of the Sonora river. Here a shaft was sunk 75 ft. deep, and the river bed cross-cut, thus securing all the water necessary. One large pump with a capacity of 1,500,000 gal. was installed in 1904, while the old and smaller pump is kept in reserve for use in times of emergency. The pumping station is 1000 ft.
below the level of the town and smelter, so that taking into account the loss of head due to friction, and the elevation of the tanks, the pumps work under a head of 1350 ft. The water main is a 10 in. wrought iron pipe.

At the Capote mine, on the six-hundred level, considerable water has been encountered. This is pumped to the surface, and flows by gravity through a wooden flume to the concentrator where it is used in the mill. Shaft Veta No.2 furnishes about 125,000 gallons and shaft Veta No.5, 30,000 gallons daily.

Geology.- "The composition of the Cananea group is that of a series of intrusive volcanic necks and dikes of Tertiary age pushed up through a pre-existing floor of early Paleozoic limestones and quartzites, and surrounded, especially to the north by vast quantities of stratified tuffs, ashes and other volcanic ejecta, which have a thickness of several thousand feet and may represent the products of old volcanic cones, the summits of which have long since been removed by erosion". The limestone and quartzites are of the same type as those of southern Arizona. But the quantity of limestone here is much less than at Bisbee, and that which does occur is more crystalline and altered. Of the igneous rocks represented here, those recognized by R. T. Hill are "white granite, two types of quartz porphyries, a basic andesite porphyry, diabase and diorite".

"There is every evidence of a continuous narrow fault-zone extending from the northwest to the southeast throughout the whole mountain, and that the mineral deposits occur in fissures identical to this fault-zone". This fault line forms the quartzite foot wall of the Capote-Oversight mine and it also passes through the Elisa mine. This main fault is paralleled to the northward for half a mile or more by many accessory faults and slips, thereby constituting a narrow zone of fissuring which, mineralogically, at least, is limited in the latter direction by the
barren porphyry belt. All the ore deposits are found within this narrow belt or zone”. The Cobre Grande and Elisa mines are true fissure types, and show a well defined hanging and foot wall, with an ore bearing vein varying from a few inches to twenty feet in width. The deposits in the Veta, Capote and Oversight are of an entirely different type and as described by Mr. Hill - "are so irregular in their apparent boundaries or lack of definition, due to replacement spreading outward from fractures that they are confusing and perplexing to those who have been accustomed to ore deposits between regular walls and give rise to the frequently repeated fears of discontinuity of ore in depth. But this irregularity of outline is more an expression of intensity of mineralization than cessation... ".

Ores.- All of the ores are very siliceous, containing (see analyses) from 10% to 40%, and sometimes more, silica, and as a result necessitate the addition of a large quantity of barren iron and lime for fluxing purposes. The Elisa ore contains 15% to 20% lime and is a very desirable ore for smelting purposes. Another good feature of the Elisa ore is its hardness, so that it sustains the burden of the furnace excellently; the copper in this ore is chalcopyrite and some bornite. The ore from the Capote, Veta and Oversight is soft and lumpy when it comes from the mine, and upon being exposed to the air makes very readily, making a large amount of fines, and an enormous quantity of flue dust is the result.

Nearly every variety of copper ore is represented here, beginning with the carbonates under the leached put gossan through the oxide zone, chalcocite, native copper and down to the unaltered chalcopyrite. Pieces of native copper weighing
from 50 to 500 pounds have been taken out of the Veta Grande mine. In the Cobre Grande mine are some beautiful specimens of chalcotrichite. The sulphide ores are the ones that yield practically all the copper turned out of the smelter.

The Capote-Oversight ores mostly occur in a crushed and decomposed phophry which is very soft,—in fact contains a large amount of talc and kaolin. It is easy to dig out, but at the same time rather expensive mining on account of the broken ground "swelling" and crushing the timbers which completely close up a new drift in a very few weeks time. The Veta ore contains more quartz and stands much better. The only way in which many of the drifts can be kept open is by continually cutting out the soft rock as it swells out and comes in contact with the timbers.

Fig. 2 shows in plan the three principal mines, together with the topography. I have no data by which to show accurately the outlines of the ore bodies, hence have left these out, and even if I had this information I would not feel at liberty to use it. Fig. 1 (Drawn by the author in July 1904 to be reproduced in the Annual Report) shows a cross-section through these mines, with the Oversight about 1000 ft. in the background. Above the Oversight and Veta can be seen open-cut workings. These are where rock and dirt are quarried for the purpose of filling in the open stopes. Fig. 9 is taken on drift 1-4 (line A-B) Oversight, and near the end of Motor Tunnel No. V-9, and shows how the filling is run into the stopes. Fig. 8 shows this same stope in plan, and Figs. 3 to 7 show the different floors.

Mining. —Considering the time these mines have been in operation, the labyrinth of underground workings is enormous,—about thirty miles of drifts, cross-cuts and tunnels.
All of the work done at the Veta, Capote and Oversight mines is square set stoping. As a rule, at present, the ore body is laid out in blocks 50 ft. square with drifts numbered similar to those shown in Fig. 8. Stoping is commenced on the sill floor and each alternate section (Fig. 8) is worked out, leaving the other sections for pillars. Car tracks are placed in each drift, and there are usually four to six double chutes for each block. One side of the double chute is used for the high grade ore and the other for the lower class or concentrating ore. Between these chutes one compartment is left open as a manway to allow the men an entrance and exit to and from the stope. Some of the chutes have only two compartments, one of which is reserved as a manway.

As soon as a few sets are taken out on the sill floor, work is then started by a raise (to be used as a chute later) and from this stoping is begun on the second floor. From here the raise is continued until it reaches the level above and is used for filling. At each set of the raise, stoping is begun, so that work is carried on simultaneously on five or six floors. Each floor is covered with 2 in. plank to afford working room for the miners, and at the same time afford protection to the men on the lower floors. As soon as the filling reaches up to a floor the 2 in. plank are taken out and used at other places. The loss of flooring timber is about 10% every time it is moved. The filling is usually kept up to within three or four sets of the face. In the majority of cases this filling consists of waste material from prospect and development drifts on the upper levels, and in a number of instances these raises have been carried to the surface (Fig. 1) and obtain filling from open cuts directly over the stopes. These raises also furnish air in the stopes. As they are open from one level to another, there is usually a good strong current of air passing through.
and many times it is very difficult to keep a candle burning while climbing up or down a manway. This of course is particularly true where each level is entered by a tunnel in the side of the mountain.

The practice of stoping out the sill floor sets is not what I consider the best, for the reason that by the time the stoping has reached seven or eight floors the burden on the lower timbers is so great that they tend to settle and when they are out of plumb, they will in a very short time, fall and crush, and thus close up the drifts so that it is almost impossible to get cars through without retimbering; while if the sill floor were left in tact, the solid ore body would support the weight, and by cutting out a little from behind the drift timbers, the passage ways could be very easily kept in fair condition until the top of the stope is reached. The sill floor ore could then be taken out as the top set for the stope coming up from below, and no ore loss would be suffered. The greed for an increased output of bullion is the cause of this practice, and in many cases it looks as though the present were the only time taken into consideration, although entailing an expense to be paid for dearly six months or a year later. The items into which this expense may be divided are: a large amount of additional timber, an extra force of timermen, and many delays caused by the closing of the drifts so that it is impossible to obtain ore from certain stopes. Of course a portion of this extra expense may possibly be balanced by the fact that this sill floor ore gets to market sooner and thus saves interest on tied-up resources; but so long as plenty of ore can be obtained to keep the reduction works running to their full capacity, that is all the ore that it is necessary to take from the mine,—the balance to remain as ore reserves.
When the alternate sections have been stoped to the top, work is then begun of the pillars, and is carried on in nearly the same manner, except not quite so wide,--carrying up only two to four sets in width at a time until all is out, or until, as often happens, a cave occurs and puts an end to work in that particular place. Considerable ore is lost in this way, but I have no means of giving a percentage. In many cases when these caves occur the ore becomes so badly crushed that much of it can be drawn out from below without stoping. I have seen a number of places where two or three men would be kept shoveling for months from the same place, making no apparent progress, but at the same time sending out a large amount of ore. This offers a hint that possibly the caving system could be used cheaper than trying to timber so much; yet this has not been done except where the caving has been accidental. After the ground has become firm again, stoping and timbering are again resorted to, and the remainder of the pillar taken cut.

On account of some very soft ground in the Capote, it is now proposed to make the stope blocks 25 ft. by 50 ft, instead of 50 ft. square.

To prevent damp, heavy ore from packing in the chutes when dropped from 50 to 100 ft. a scheme as shown in Fig. 10 is resorted to, and it works admirably well. Two 10 in. by 10 in. timbers are placed at the top of each set and thus forms a breaker for the ore, throwing it across to the opposite side of the chute where it encounters another set of horizontal timbers and is again deflected in its course, so that its velocity of falling is greatly reduced.

Air drills are used in driving the main drifts when the ground is very hard. In the stopes "single-jacks" are used exclusively. At the Oversight, much of the ground is so soft that hand augers are used and holes bored in the same manner as
a carpenter would bore a hole in a stick of timber. Dynamite is used in blasting.

At the Elisa mine very little timbering is done. The ore occurring as it does in a true fissure with solid walls, and in a siliceous limestone stands well when opened. In all the stoping the overhand method is used; the stopes are 10 to 25 ft. wide, and 75 to 100 ft. long. The ore is broken down from the roof and hand-picked in the mine, leaving the waste rock for filling; additional waste is dropped in from the upper levels so as to keep the floor of the stope within 8 or 10 ft. of the roof. Upon this floor scaffolding is erected by placing 2 in. planks on large boulders or on piles of waste. Chutes are made of 2 in. plank and built up in the waste so that the top is kept level with the floor, thus making it an easy matter to dispose of the ore. The ore is trammed from the chutes in small mine cars, by men, to the railroad ore bins, a distance of 1500 ft.

Timbering.—Fig. 13 shows the method of timbering a three-compartment shaft. The wall and end-plates are each 12" by 12 in. The corner posts are also of the same size. The side posts and ties (struts) are 10 in. by 12 in.; the posts are 4 ft 2 in. long, making each set of wall plates 5 ft. center to center. In the illustration it will be observed that the tie marked "A" has the dovetail tenon cut with the narrow edge down, while "B" has the narrow edge up. The reason for this is so that "B" can be left out until after the posts are set to allow sufficient space to put the next lower wall-plates in position. Of course if the shaft is sunk 10 or 12 ft. below the timbering, this would not be necessary; but then scaffolding would have to be used to put the timbers in place. In soft ground it is absolutely necessary to keep the timbers close to the bottom. As soon as the next set of wall-plates are in position, the tie "B" is then inserted from the under side, and the post placed under it and on the wall-plate.
below, again leaving out one tie as before.

Each hoisting compartment is 4 ft. by 5 ft. in the clear, while the pump compartment is 5 ft. by 7 ft. giving ample room for pumps, electric light wires, air and steam pipes, and a ladder that can be used in an emergency.

The guides G, G, are made of 4 in. by 4 in. timbers and securely bolted to the ties. The shaft is generally boarded up with two or three inch plank placed vertically on the outside of the timbers. Sometimes ordinary lagging is used and placed horizontally behind the posts. The ends of the wall and end-plates are held together by means of a 1 in. hardwood pin driven in the holes as shown. To prevent the timbers from settling, 1 in. iron rods or bolts (called hangers) are extended from one plate to the next lower and the nuts screwed up tight, so there is no danger of a separation of the timbers vertically. In addition to this they are thoroughly wedged against the wall rock.

The timbers used in stope-work are of Oregon pine, 10 in. square, and are cut as shown in Fig. 11. The sets are 5 ft. center to center. The sill floor set is 8 ft 6 in. high, while the regular stope sets are 7 ft. 4 in. The tunnel-set timbers are of the same size (unless in very soft ground, when 12 in. posts are used), and have a batter of 1 ft. in 7 ft. 3 in., and for double-track drifts the cap is 5 ft. 10 in. in the clear. The posts are set at the sides 5 ft. center to center. In solid ground no sill is used; simply a 3 in. block placed under the end of the post. Four inch square (or 4 in. by 6 in.) timbers are used for track ties, and for double tracks are cut long enough for both tracks allowing 16 in. between tracks. Fig. 12 shows a two-compartment shaft or winze timbers.

The following table gives the number of square sets of ore that were actually taken out during a period of five months, which makes a total of 2,304 213 cu. ft
<table>
<thead>
<tr>
<th>Month</th>
<th>July</th>
<th>August</th>
<th>Sept.</th>
<th>October</th>
<th>November</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of set</td>
<td>9' 7' 4&quot;</td>
<td>9' 7' 4&quot;</td>
<td>9' 7' 4&quot;</td>
<td>9' 7' 4&quot;</td>
<td>9' 7' 4&quot;</td>
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**CAPOTE MINE:**

<table>
<thead>
<tr>
<th>Level</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>First Level</td>
<td>3</td>
<td>378</td>
<td>326</td>
<td>283</td>
<td>362</td>
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<tr>
<td>Second &quot;</td>
<td>13</td>
<td>7</td>
<td>114</td>
<td>7</td>
<td>224</td>
</tr>
<tr>
<td>Third &quot;</td>
<td>1</td>
<td>2</td>
<td>57</td>
<td>2</td>
<td>144</td>
</tr>
<tr>
<td>Fourth &quot;</td>
<td>57</td>
<td>2</td>
<td>144</td>
<td>140</td>
<td>259</td>
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**VETA GRANDE MINE:**

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<tr>
<td>First Level</td>
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<td></td>
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<tr>
<td>Second &quot;</td>
<td>2</td>
<td>405</td>
<td>9</td>
<td>207</td>
<td>444</td>
</tr>
<tr>
<td>Third &quot;</td>
<td>3</td>
<td>374</td>
<td>505</td>
<td>373</td>
<td>717</td>
</tr>
<tr>
<td>Fourth &quot;</td>
<td>1</td>
<td>134</td>
<td>1</td>
<td>214</td>
<td>170</td>
</tr>
<tr>
<td>Fifth &quot;</td>
<td>57</td>
<td>2</td>
<td>144</td>
<td>140</td>
<td>259</td>
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**OVERSIGHT MINE:**

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<tr>
<td>C9</td>
<td>60</td>
<td>153</td>
<td>38</td>
<td>211</td>
<td>229</td>
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<tr>
<td>C4</td>
<td>18</td>
<td>364</td>
<td>371</td>
<td>336</td>
<td>47</td>
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<tr>
<td>C5</td>
<td>2</td>
<td>224</td>
<td>240</td>
<td>220</td>
<td>213</td>
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**COBRIN GRANDE MINE:**

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<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>First Level</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second &quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td>20</td>
<td>4</td>
<td>19</td>
<td></td>
<td></td>
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</tbody>
</table>

**T O T A L S**

| | 108 | 2043 | 107 | 2190 | 280 | 1954 | 401 | 2458 | 369 | 2481 |

The amount of timber required per set is 400 ft. (board measure) and equals 2 1/6 sq.ft per cubic foot of ore extracted. By taking 12 cu.ft. of ore in place for one ton it requires 26 sq.ft. of lumber per ton of ore, and at $30.00 per M. is 78 cents per ton of ore. To this should be added something for waste and also an item for extra timbering and the replacing of crushed timbers, so that the cost of this item of expense in mining here is very close to 90 cents per ton.

The amount of lumber actually used during the month of December was
1,292,220 feet (board measure). The amount of ore extracted was approximately the same as for the month of November, which gives 87 cents (gold) per ton of ore for timbering expense.

Drift numbering. - In the early days of practically all organizations well outlined systems are far from perfect, and in many departments such a thing as system is unknown. This is true with reference to the numbering of the drifts in these mines, and is not yet entirely overcome. Until about one year ago all of the drifts were numbered chronologically. The only resemblance to system was in the different levels, where the digit in hundreds place indicated the level, thus: All numbers from 100 to 199 were reserved for the first level workings; 200 to 299 for the second level; 300 to 399 for the third level and so on. But with reference to the location of a certain drift on any level, the numbers indicated nothing, for at one end of the mine would be drift 110 and at the opposite end, perhaps 500 or 1000 ft. away would be drift 111, and then in a few days drift 112 would be started from drift 101, and then drift 113 might start from 110.

The scheme that has been inaugurated to supplant this systemless system is best illustrated by the sill floor of the stope-sheet Fig. 8. The working shaft is sunk in either the foot or hanging wall (footwall here) for the purpose of having it in solid ground that will not be subject to caving when the ore is mined. A double drift, 1-F is driven from the shaft (winze here) approximately at right angles to the strike of the ore body. In this case 1-F was used for it was known that ore existed to the left of this drift, and this provided for five other drifts (A, B, C, D & E), some of which will be driven later. These drifts designated by letters...
have a drift No. 100 which runs at right angles to them, and is usually placed in the foot-wall or barren ground. The number placed before the letter indicates the level; thus, 1-F, 1-4, etc. are first level; 2-F, 2-B or 2-6 the second level. Now parallel to this main foot-wall drift are drifts numbered 1-2, 1-4, 1-6, 1-8, etc., on one side, and those on the opposite side, should there be any work there, take the odd numbers, thus 1-1, 1-3, etc. The ground is thus planned to be blocked out in squares of 50 ft., but it is not necessary to drive the drifts so often.

When a new drift is started, its distance from some other drift is a multiple of 50 ft., and the proper number given it. Every alternate drift is cut through to the foot-wall drift, thus affording safety drifts, and at the same time a good outlet for the ore cars.

This system is undoubtedly best applied to workings in large ore bodies, yet in a modified way it can be applied to almost any underground workings if only a little planning is done ahead.

Ore Transportation.- At present about 1/2 of the ore output is brought to the surface through tunnels; all of the Oversight ore is thus delivered; all of the Capote ore is hoisted at Shafts 2 and 10 to the first level (160 ft. below the surface) and from here the mine cars are taken out through Tunnel No. 1, to the railroad ore bins, about 800 ft. from the shafts. The Oversight ore is mined over 3000 ft. from the railroad Capote bins, and until April 1st of this year the one ton capacity mine cars were wheeled to the bins by Mexican labor, at $3.00 Mex. per day. This long haulage of such a large quantity of ore has brought about the installation of an electric motor haulage through the Veta No. 9 tunnel to the Oversight mine (Fig. 2) 3500 ft. from the Veta R.R. bins. This also eliminates 2 kilometers of railroad haulage which of course is quite an item. This motor system has a side track to bins 80 ft. below the surface at Shaft V.5
The track used for the motor is 36 in. gage, the same as the Narrow Gage Ry. The ore cars are of eight ton capacity and 10 cars constitute a train. The motor used is made by the Jeffrey Mfg. Co. and consists of two 35 H.P. motors in one frame. Only one unit of the motor is used in this work. The voltage of the current is 250%. Both rails are bonded, and a return circuit of copper wire is also placed on the ties alongside of one rail. The amount of power for starting the loaded train is about 28 H.P., and as the outgoing track has a minus grade of 2/3 of 1%, very little power is used; in fact, brakes have to be applied frequently. To take a train of empty cars back requires 10 H.P.

The ore is loaded from the chutes marked "C" in Fig. 2 at the Oversight. These same chutes are shown on a larger scale in Figs. 8 and 9. The time required for making a round trip (twice 3500 ft) including loading and unloading is 30 minutes. As soon as the system is in better running order, and the track thoroughly surfaced, the round trip time will be cut to twenty minutes. This one motor train replaces 75 Mexican carmen.

The ordinary mine-car tracks are 18 in. gage and 14 lb. rails are used. These are too light for long haulage of large quantities of ore, for under the constant train of loaded cars the rails will bend down between the ties, or even spread, and soon the track is in very bad condition. At all intersections of the track there are turn-sheets five feet square so that it is possible to transfer the cars from one drift to another very easily. The grade is generally 8 inches in 100 ft., sloping from the ore bodies to the shaft or exit tunnels; in the main stopes the track is practically level. An 8 inch grade is entirely too much, for one has only to watch the out and in-going cars to see that it
it requires far more labor to push back the empty, than to bring out the loaded car. The proper grade is one where the amount of labor required to push a loaded car is the same as that necessary for an empty, and it would require but very little experimenting to determine the proper grade for this.

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Fig. 14 shows the Veta Grande Mine in plan, and by comparing it with Fig. 2, its location, relative to the other mines, will be clearly shown. Fig. 15 is a longitudinal section on the line A-B,B'-C as shown in Fig. 14. Figs. 16, 17, 13 and 19 are cross-sections of the same mine. The stoping here is carried on in the same manner as shown in Figs. 8 and 9. All of the second level ore is taken out through Tunnel V 3 to bins at the N.G. Ry. Tunnel V 9 is used exclusively by the electric motor for the handling of the Oversight ore. The ore from the third and lower levels is hoisted at Shaft V 5 and dumped into the bins east of the shaft on the second level, 80 ft. below the surface. From these bins it is loaded into the motor cars and taken to the Ry. bins (see photo on last page).

Assays. - The following table gives a very comprehensive statement as to the character of the ore and the reduction products. PICKED ORE is that which is hand sorted from the second class prior to entering the crusher at the concentrator. CHAMBER DUST, that which is collected in the large dust chamber, while the FLUE DUST is that which is collected before the gas and smoke reach the main chamber. CRUDE ORE is the sample taken after the concentrator ore has passed the crusher, and before it enters the mill proper.
<table>
<thead>
<tr>
<th>Samples</th>
<th>Cu. %</th>
<th>SiO %</th>
<th>Al O. %</th>
<th>Fe. %</th>
<th>CaO %</th>
<th>S. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capote Ore, 1st Class</td>
<td>6.65</td>
<td>39.0</td>
<td>7.7</td>
<td>17.3</td>
<td>19.8</td>
<td></td>
</tr>
<tr>
<td>&quot; &quot; 2nd &quot;</td>
<td>3.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oversight ore, Special</td>
<td>10.43</td>
<td>22.6</td>
<td>14.8</td>
<td>17.1</td>
<td>23.9</td>
<td></td>
</tr>
<tr>
<td>&quot; &quot; 2nd Cl.</td>
<td>4.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elisa Ore</td>
<td>5.35</td>
<td>27.2</td>
<td>5.3</td>
<td>15.3</td>
<td>19.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Veta Grande Ore</td>
<td>13.10</td>
<td>44.2</td>
<td>11.9</td>
<td>6.5</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Picked Ore</td>
<td>9.03</td>
<td>22.0</td>
<td>9.5</td>
<td>22.3</td>
<td>25.5</td>
<td></td>
</tr>
<tr>
<td>Concentrates</td>
<td>9.65</td>
<td>15.4</td>
<td>5.1</td>
<td>30.9</td>
<td>37.4</td>
<td></td>
</tr>
<tr>
<td>Concentrator Tailings</td>
<td>1.19</td>
<td>62.0</td>
<td>21.5</td>
<td>1.8</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>Puertecitos Ore</td>
<td>7.62</td>
<td>33.2</td>
<td>8.1</td>
<td>18.1</td>
<td>18.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Cobre Grande Ore</td>
<td>26.53</td>
<td>23.4</td>
<td>12.6</td>
<td>5.2</td>
<td>0.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Chamber Dust</td>
<td>10.97</td>
<td>29.4</td>
<td>11.1</td>
<td>26.7</td>
<td>2.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Flue Dust</td>
<td>10.77</td>
<td>24.8</td>
<td>6.9</td>
<td>31.2</td>
<td>1.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Iron (For Flux)</td>
<td>4.0</td>
<td>2.9</td>
<td></td>
<td></td>
<td>61.0</td>
<td></td>
</tr>
<tr>
<td>Lime &quot;</td>
<td>4.0</td>
<td>1.2</td>
<td>1.1</td>
<td></td>
<td>51.4</td>
<td></td>
</tr>
<tr>
<td>Converter Clay</td>
<td>59.6</td>
<td>21.1</td>
<td>3.8</td>
<td>2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica (Conv. Lining)</td>
<td>85.2</td>
<td>7.6</td>
<td>1.7</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matte</td>
<td>61.6</td>
<td></td>
<td>17.6</td>
<td></td>
<td>19.2</td>
<td></td>
</tr>
<tr>
<td>Slag</td>
<td>0.27</td>
<td>36.8</td>
<td>12.7</td>
<td>29.3</td>
<td>12.1</td>
<td></td>
</tr>
<tr>
<td>Bullion</td>
<td>99.20</td>
<td>11.2</td>
<td></td>
<td>0.10</td>
<td>oz Gold</td>
<td></td>
</tr>
<tr>
<td>Crude Ore</td>
<td>4.43</td>
<td>55.0</td>
<td>12.8</td>
<td>9.1</td>
<td>9.9</td>
<td></td>
</tr>
</tbody>
</table>
Reduction works— It is not the purpose of this paper to give a detailed account of the reduction of the ore mined here, but it will certainly be of interest to know what becomes of the enormous quantity of ore mined as described in the foregoing pages. The ore mined will run from 3% to 10% copper (see analyses), and as it is brought from the mines, it is divided into first and second class—the first class taking all the ore above 4.5% and the second, all below this. The ore from the "first class" bins is taken direct to the smelter where it is smelted to a 60% matte. The ore, as the analyses show, is very siliceous and requires a large amount of fluxing material (iron and lime), and unfortunately this material is barren so far as copper content is concerned. The furnace-charge is approximately as follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper bearing ore and concentrates</td>
<td>52.38%</td>
</tr>
<tr>
<td>Coke</td>
<td>11.49%</td>
</tr>
<tr>
<td>Iron ore</td>
<td>14.63%</td>
</tr>
<tr>
<td>Limestone</td>
<td>9.84%</td>
</tr>
<tr>
<td>Chips and slag</td>
<td>5.30%</td>
</tr>
<tr>
<td>Flue dust</td>
<td>9.36%</td>
</tr>
</tbody>
</table>

The low-grade ore is concentrated to a product carrying about 10% copper and from here it is added to the blast furnace charge. While the concentrates are quite fine, this material is a very desirable addition to the charge on account of the high percent of sulphur and the small amount of silica it contains; but one objection is urged against it, and that is the excessively large amount of flue dust which it produces, over 100 tons daily, practically all of which is collected in the dust chamber. From here the dust is passed through the mud-mill and briquetting machine, is sun-dried and again charged in the furnace. A portion of the dust is shipped to El Paso to be smelted. The reverberatory furnaces which are now under construction will take care of all the dust, as well as the fines from the concentrator.
The matte is tapped from the furnaces (eight in number) into settlers, and from here it is drawn out into large ladles which are handled by an electric crane, and the matte is poured into Bessemer converters (five stands). Here the iron in the matte is taken up by the silica lining of the converter forming a slag, while the sulphur is oxidized to sulphur dioxide and passes out to the air. The copper is drawn off as almost pure bullion, 99.2%, and also contains the little silver and gold which the ore carries. This bullion is molded into ingots of 300 pounds each; the rough edges and corners are trimmed off, and the bullion is then loaded into cars for shipment to the refinery. Such is a short resume of the ore after it leaves the miners' hands. The cost of producing copper here, according to the President's report, is a fraction less than 8 cents per pound.

Extract from Annual Report.—"The output of the mines during the year was 489,352 tons of ore, and 147,099 tons of fluxing materials, limestone and iron. Development work comprised 7,483 ft. in the vertical direction and 27,207 ft. in drifting and tunneling. A large part of the mill was remodeled during the early part of the year, so that nearly two-thirds of the year's output was made in the latter half. The ore treated amounted to 207,224 tons net, and the output of the concentrator was 59,065 tons, showing a ratio of 3.51 to 1. Since full operations were resumed the daily capacity (of the concentrator) has averaged 900 tons, at a cost of 7.6 cents per ton.

"The smelter treated 308,215 tons of ore and concentrates, an increase of 33.3% over the preceding year, at a cost of $1.40 per ton less than the average for that year, but without any additions to the equipment. This result was accomplished by more careful attention to the details of the process, one outcome of which was to reduce the proportion of coke in the charge by 26.7%.

"The output of the smelter during the year was,
"Copper (electrolytic assay)........59,915,947 lb.
Silver.................................505,702 oz.
Gold..........................3,569 oz.

"The profit for the year was $1,075,315 in which the value of the stocks on hand were estimated at cost. From this an appropriation of $107,988 was made to cover depreciation of plant, leaving a balance of $967,327 for distribution, $518,000 of which was paid out in dividends". The capitalization is $8,640,000.

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No effort is made to keep any record of the geological developments as the work of the mine progresses. All such data are preserved only in the heads of the various foremen and, therefore, so far as being available for the guidance of future management, it is of no significance whatever. As an improvement upon mining methods here, it seems to me that it would be good policy to have one man on the engineering party who is a geologist to work in conjunction with the surveyors and collect data to be used on a geological map. Of course this need not require all of his time, and he could be of other assistance to the engineer. So far as I can observe it seems to be the policy of the management of the mining department to ignore and even discourage the collection of such data. Whether it is because the value of such information is not appreciated, or that some definite geological knowledge might be divulged, I do not venture to say; although I am inclined to think it is the latter. It would be a great aid to prospecting and development work if accurate records of faults, fissures, contacts, ore outlines, and the character of the rock encountered were all mapped. With this data at hand it would give a substantial basis from which work could be systematically planned and carried out, and also would be of very material assistance in making estimates of probable ore reserves.
Practically all the prospect work has been on the surface, the deepest shaft being only 700 ft. At Bisbee, the new companies do not hesitate to sink a shaft at least 900 to 1200 feet and then work out. But here, a large concern with millions invested has not in six years time hoisted a pound of ore from a depth of 700 ft.; nor they know that any ore exists on that level. It is true that shallower workings have furnished all of the ore that could be handled, but these are being rapidly exhausted, and no knowledge of deeper levels is at hand. Of course shaft sinking is expensive, but diamond drills can be operated at a reasonable cost and a large number of holes can be put down 1000 ft. for the same amount a shaft would cost.

Some prospecting has been done with diamond drills. These holes have been plotted on the maps but as to what has been encountered is closely guarded in some mental storehouse, as being a safer place than on paper with waterproof ink. No vertical drilling has been done yet, and 400 ft. is the longest horizontal hole drilled. Diamond drill work has been carried on quite successfully in South Africa to a depth of over 5000 ft, and I see no reason why it cannot be operated here to at least 2000 ft.

Mining Costs.—This is an important item with all mining companies, but figures for the cost here are not at my disposal. All the costs I can give are contained in an extract from the Annual Report. Observation leads me to believe that the mining costs are exceedingly high. The man who holds the position of mine engineer is seldom consulted as to the cost of any proposed work. In his office no records of costs are kept, and as to the planning of new work he has but very little to say. There are many instances that I might mention where the engineer's authority is very much curtailed. The mine timbers and head-frames are designed by the head carpenter. The head-
frames thus constructed show that they are strong enough to do the duty required of them, but there is ample material in one for two good substantial frames.

Another item that indicates expensive mining is that occasionally a drift is let out by contract. These contract-drifts are driven at least twice as fast as those worked by the company, and with but very little more labor expense. It seems to me that contract work could be done to good advantage, and should the contractors finally raise their figures too high, then the company could do its own work as is now done.

Mine surveying.— With such a large amount of underground workings, scattered over an extensive territory, this work keeps one field party busy all the time, and also furnishes plenty of work for two office men.

While this is in Mexico where the metric system is standard, yet feet and tenths are used in all the mine surveying. So far, the larger part of the mining has been done through tunnels and it has been an easy matter to carry in the lines direct from the surface triangulation points. Here the trouble is not so much in getting lines in as to keep them after they are are in. So long as drifts are in good solid rock, permanent points can be set by drilling an inch hole in the roof, in which a pine plug is driven. A horseshoe nail, with a hole punched through the head, is driven into the plug. A plumb bob is then suspended from the point in the roof, and a hub driven in the ground (or a tack in the track tie) and a small brad placed in the hub directly under the bob. This is then used as the point over which the instrument is set. The backsights and foresights are usually taken on the plumb line suspended from the points in the roof. In soft ground it is impossible to keep plugs in the roof, so the next best thing to do is to drive the horseshoe nails in the caps. This is not satisfactory, for the points cannot be depended
upon after a couple of months. Many times they will move as much as three or four inches. In stoping ground it is still worse. Here the timbers break and lean over, and all transit stations are absolutely worthless, except as temporary points for the survey in question. In such ground, whenever any drift connections are to be made, it is absolutely necessary to go far back to points that are in solid rock, as a base line, and re-run the line to the face of the required drift; then with these new values of courses and distances, latitudes and departures are worked up, and the calculations made for the connecting drifts.

The angles are read to quarter minutes, and the distances to hundredths.

No deep shaft plumbing (not over 300 feet at one time) has been done here. For example, at the Veta mine the second level work was run in from Tunnels 3 and 9. Then from the second level, plumb lines were let down shaft V 5 and the third level orientated from this. The plumb lines used are fine silk cords, and the bobs weigh about 5 pounds each. For deeper plumbing 18 pound bobs are used. A bucket of water is used for quieting the bobs.

Sometimes it is possible to line the instrument in with the bobs, but this is seldom done on account of lack of sufficient room at the shaft station. It is possible to obtain a longer base line by placing the instrument in a line that is practically at right angles to the line of the bobs, and of course better results are thus obtained. The instrument is set up at Sta. 1 as shown in the following diagram and Sta. 2 is used as a backsight,
the course from 2 to 1 being known from previous surveys. Reading
the angle on the bobs gives these courses and at the same time
the angle included between the bobs and the instrument. The
triangle is then solved by the formula for the two sides, and in­
cluded angle. This gives the angles at the bobs, from which the
course of the line between the bobs is easily obtained. The in­
strument is then taken to the lower level, and set up in a similar

position and the angle between the bobs and instrument is read,
and at the same time a point is placed ahead, or a permanent point (a)
put in one of the shaft timbers, and sometimes both. From the
work on the upper level the course between the bobs is known, then
by the solution of the triangle below the angles at the bobs
are known, and the course from each bob to Sta. 1 is obtained, and
also from 1 to 2. These two points furnish a base line for the
work on that level, until at some distance (300 or 400 ft) from
the shaft a raise is connected with the upper level. This gives an
excellent opportunity for check work, and the method is as follows:
The day before plumbing a traverse is run from some reliable
points, and a point established at the shaft, and one also at
the winze where the bob is to be suspended. This is also done
on the lower level. Then on the following day (for it usually re­
quires two days), a bob is let down the shaft and one down the
winze. The instrument is set up at the points previously set and
a course and distance measured to the bob in the shaft, and the same
thing is done at the winze. Immediately after this is done, the
Sketch showing method of plumbing from one level to another, giving actual figures as obtained in this particular case.

<table>
<thead>
<tr>
<th>Level</th>
<th>Bob in Shaft C10</th>
<th>Winze</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 Level</td>
<td>-410.27</td>
<td>337.12</td>
<td>403.17 ft</td>
</tr>
<tr>
<td></td>
<td>Winze</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course</td>
<td>245° 23'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 Level</td>
<td>-615.27</td>
<td>337.12</td>
<td>401.25 ft</td>
</tr>
<tr>
<td></td>
<td>Winze</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course</td>
<td>245° 24'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Difference: -0.18' (0.10')

Correction in course on 600 level = +0° 01' 10''

The original course on the low level was obtained from the pegs in Shaft C10, from the same section peg.
instrument is taken to the lower level and readings and measurements taken to both bobs. This completes the field work.

The notes for the second level traverse are worked up, obtaining the latitudes and departures of both bobs. From these, a course and distance is calculated between the bobs. This usually gives a base line 300 ft. or 400 ft. long with a true course.

The notes for the lower level are worked up in the same manner as above, using the latitude and departure of the bob in the shaft as obtained above as the starting point for the lower level totals, and if the latitude and departure check at the winze within 3 to 5 hundredths, the work stands as obtained from the original plumbing. But owing to the difficulties of plumbing down a shaft, with a base line of only 4 to 7 ft., air currents and water, there is usually a difference of 0.3 to 0.5. In this event, a course and distance is calculated between the bobs from the latitude and departure as obtained on the lower level. This gives the course as actually carried down the shaft in the first place. The difference between this course, and the one on the upper level, is the correction to be made, either as a plus or minus, as the case may require. All the previous courses are corrected by this amount and a new set of latitudes and departures worked out for the new courses (The correction seldom ever amounts to more than 2 to 4 minutes). For any level below this one, at a later period these corrected courses are used as a basis for plumbing, and as the work progresses and winze or raise connections made, check work is again applied as above.

All courses are carried in azimuth in the office note books; the instrument man simply reads the angles, with the instrument set at zero on his backsight, and the courses are calculated in the office. For working maps in the office, the traverse lines only are plotted on clothbacked paper; scale 50 ft. to 1 in. The stope maps are kept as shown in Figs. 3 to 8. Plan maps similar to Fig. 14 are also kept up and furnished to the mine foremen.