Engineering and geological work at Cananea, Mexico

Edward Dale Lynton

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ENGINEERING AND GEOLOGICAL WORK AT CANANEA, MEXICO.

BY

EDWARD DALE LYNTON

A

THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the
Degree of

ENGINEER OF MINES

Rolla, Mo.

1915

Approved by

[Signature]

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The purpose of this thesis is to relate in as clear and concise a manner as possible the way "things are done" in practice as observed by myself during my two years' experience as sampler and assistant geologist to the Cananea Consolidated Copper Co. of Cananea, Sonora, Mexico. My work took me to all the mines, and in this way I was able to accurately observe the sampling, system of mining, geology, etc., of this famous and important camp.

Not being in a position to explain research work or lengthy experiments, I am going to attempt to give in this thesis, some practical hints that might be of interest to a student. The average graduate from college has very little practical experience concerning mining and so I hope that any one reading this will derive a little more benefit than if it were some lengthy technical research. During my stay in Cananea, I took numerous photographs around the mines and camp and as many as these as are relevant to the subject will be shown.
CANANE A.

This mining district was discovered in 1865 and developed in 1899 by Wm. Greene, who for many years was the largest owner. It was not until a few years before his tragic death in a runaway accident in 1911 that he retired from the active management of the properties.

Cananea is situated in the district of Arizpe in the state of Sonora in Mexico, forty miles from the American border. It lies at the foot of the Cananea mountains, the land to the border being a flat prairie and slightly undulating. The population is nearly all Mexican, although there is a large number of Americans and Chinese with a sprinkling of Germans, French, and foreign nationalities, making the total number at present about ten thousand.

The town has an American colony, situated on a mesa, the Mexicans and Chinese having their own settlements in other parts of the camp.

The Cananea Consolidated Company has a concentrator; the largest copper smelter in the southwest; and certainly one of the best power plants in the country. The mines, numbering about fourteen, lie on a zone S.E. by N.W. stretching about ten miles. Most of the active producers are located at Chivatera, some three miles above Cananea.
THE GEOLOGICAL DEPARTMENT.

This department supervises many branches, among which are model making, sampling, both groove and grab samples, the underground geology of all the mines, surface geology of the Cananea district and the outlying claims. The most important branch is the recommendation to the general superintendent of mines of drifts for prospect work. There is no doubt that in this, the department has been very successful and by locating good ore bodies has paid for itself over and over again. Yet another branch is the mapping of stopes by Brunton survey, and the geology and sampling of the stopes also. All the Mexican leases of the Company's ground has been put under this department. All of this, of course, entailed a great deal of mapping and I will cover every subject of this matter in detail in their proper order.
Maps

All the mapping is done by the engineering office and copied on a hard copy, scale 1" equals 50'. There are two mines to a hard copy and only the traverse lines with the instrument station numbers are copied. The levels are in different colors as follows:

<table>
<thead>
<tr>
<th>Level</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>orange</td>
</tr>
<tr>
<td>200</td>
<td>green</td>
</tr>
<tr>
<td>300</td>
<td>brown</td>
</tr>
<tr>
<td>400</td>
<td>carmine</td>
</tr>
<tr>
<td>500</td>
<td>violet</td>
</tr>
<tr>
<td>600</td>
<td>dotted orange</td>
</tr>
<tr>
<td>700</td>
<td>green</td>
</tr>
<tr>
<td>800</td>
<td>brown</td>
</tr>
<tr>
<td>900</td>
<td>carmine</td>
</tr>
<tr>
<td>1000</td>
<td>violet</td>
</tr>
</tbody>
</table>

The co-ordinates are all numbered from zero up, and are 6" apart or 300'.

From these hard copies, the geologists obtain their data and trace the drifts on to their maps of tracing cloth. These maps are 29" x 30" and will so fit together that they will make a complete map of the camp. One map generally covers one level, but should the level run off and come onto another map, this map will come under the name of "north, south, east or west" whatever it is, such as, "Capote Mine 100 level, east."

Geology Maps. On these 29" x 30" maps is kept the underground geology, formations being penciled in colors. There is also a map of this size for the surface geology of that particular mine. The traverse lines are not put on, but the drifts are 5' in width and to scale, for the traverse lines are always taken as being the center of the drift.

Sample Maps. As the groove samples are taken in the
mines, a sketch is made with the number of the sample put on, and when the assay returns come in, a map is made on tracing cloth to fit the purpose, though no map smaller than 12" x 12" is made. The assays only are put on and not the number, though the original sketch is kept for reference.

**Stope Maps.** Scale 1" equals 50'. The stopes were originally kept in a large book of co-ordinated paper, one sheet to each floor of the stope. Later the system was changed and instead of co-ordinated paper, tracing cloth is used, for this enables one to put the maps, one above the other and see distinctly the floors of the stope fit one above the other. From these maps, all the data for the models of the mines were taken.

**The "Hundred-foot" Maps.** The office keeps two of these maps and they cover the whole camp from the Cananea-Duluth mine in the southeast to Puertecitos in the northwest. On the one is shown all the drifts, tunnels, shafts, roads, etc. and some of the important surface geology as well as the contacts only in the drifts. The other map is kept for surface geology only. Scale 1" equals 100'.

**Underground Sheets.** These maps are made on tracing "bank note paper" and so divided that nine of them exactly fitted and covered one of the 29" x 30" geology maps. These sheets are put together and fastened inside a cardboard cover forming a neat book. There is one book to each mine. The drifts are brought up to date from the 29" x 30" maps and then the books are carried underground where the geologist plots the geology so that in turn he can bring up to date the geology on the 29" x 30" maps.
MINE MODELS

The purpose of making these models is to put before the mining department the different mines in some tangible form, so that it will show in a clear manner how the ore bodies lie and in a way help to direct the prospect work.

The first mine model made to the scale of 1" equals 50' and fully completed, was that of the Capote, though several others were made but not as completely finished, so by giving a full description of the Capote model the same can be applied to all the others.

The mine is 1000' deep, comprising 10 levels, approximately 100' apart. Several shafts have been sunk but only two remain open and are of importance, No. 2, an old shaft, four compartment, up two of which all ore was hoisted, the remaining two compartments being, one for the men and the other for a manway. No. 15 shaft was sunk to the 1000' level and was being sunk still deeper, hence no ore was hoisted up it.

To represent the levels, ten pieces of the best plate glass, \( \frac{1}{4} \)" thick and about 30" x 30" were used, valued at about $2.00 each. One plate glass was taken and thoroughly cleansed of all grease marks, placed upon one of the geology maps and the co-ordinates carefully traced with a ruling pen, using Sherwin-Williams black buggy paint, diluted to the right thickness. Then the drifts, shafts, raises, tunnels etc. were traced and the drifts were filled in in black with Jap-a-Lac varnish. This gave the map a dull black finish and made the
drifts show up prominently when the levels were all set up one above the other in their proper order. The outline of the sill floor of the stope in dotted lines was put on to locate its position on the glass. It was after many experiments that the above mentioned paints were used and it they were found to give good satisfaction.

The next step was to design a steel frame with adjustable supports for the glass, so that the levels could be adjusted to their correct elevations. The whole was on rubber rollers and could be taken apart; the cost of such a frame being about $20.00. An oil cloth cover to slip over it was made with one side that could be unbuttoned, and the model could thus be shown without having to take off the whole cover. This was found to keep out the dust and do away with the necessity of cleaning the glass and models frequently. The cost of this cover amounted to approximately $3.00.

We now come to the actual model making, though at first, it is necessary to digress and explain the method of stope mapping.

In driving a raise from one level to the next, the distance between the sets is 7' 4" except the set on the sill floor which is 9'. Hence on an average it takes from 13 to 14 sets to connect one level to the next, or in other words, a stope mine from one level to the next has 13 or 14 floors to it. The part of the stope on the level itself is called the sill floor or the first floor, the second floor is the first set up or 9' above the sill. To make clear the explanation the following table is used:
1st floor equals sill floor 9th floor equals 60' up
2nd " " 9' up 10th " " 67' 
3rd " " 16' " 11th " " 75' 
4th " " 23' " 12th " " 82' 
5th " " 31' " 13th " " 89' 
6th " " 38' " 14th " " 97' 
7th " " 45' " 15th " " 104' 
8th " " 53' " 16th " " 111'

The extra foot added on every third floor is accounted for by the 4" above 7' in the height of the timber.

As the ore body is mined out beginning on the sill floor and on up through to the fourteenth floor, a map is made showing accurately the dimensions and shape of the stope at each floor. So when the stope is finished and filled, there always remains an accurate record of it. This record is kept in a book and from these stope maps, a model of the mines is taken.

The models of the stopes is built out of transparent celluloid, light brown in color, about one-eighth of an inch thick, just so that the thickness of the celluloid represents one floor of the stope. The stopes are traced on tracing paper and pasted on the celluloid, then sent to the saw mill where the outline of each floor is cut out.

In the office each celluloid floor is placed one upon the other in their proper order, the sill floor, of course, being on the bottom, and the top floor coming just below the sill floor of the level above. Great care is also taken that the celluloid floors fit one above the other in their proper relative positions, then they are glued to each other by means of a drop of alcohol. Alcohol seems to dissolve the surface of the celluloid and on drying weds the two pieces together very firmly. Shellac was at first tried but it stained the
celluloid and also was not as strong in small quantities as the alcohol.

The stope being firmly put together, it is placed in its right position on the glass. In time all the stopes in the Capote were made and placed in position. Strips of celluloid about 2" long are cut to represent the shafts on each level, also all the prospect raises to scale according to the height to which they are driven. These, in order to show prominently, are painted black.

A few powerful lights are placed at the bottom of the frame and by electric lighting, the whole model shows up very beautifully. A good photograph of the Capote model can be seen on the opposite page.
MINE SAMPLING

Whenever a drift or a raise is being run in any one of the mines, the shift bosses both on the day and night shifts take a grab sample from the "muck" pile after the men fire their round. Every day the resulting assays from these samples are turned into the geological department and if a raise or drift seems to be running ore,—that is 1.5% Cu.—fairly consistently, it is decided to sample it accurately by grooving.

The grooves are cut by Mexicans who are paid $4.00 a day Mexican currency. Their outfit consists of (1) a 7' x 5' canvas (2) 4 lb. single jack (3) from 6 to 12 moils (4) a large sized geological pick (5) cement sacks in which to put the samples (6) cardboard tickets to mark the samples.

When a drift requires sampling very accurately, grooves are cut along both walls horizontally or vertically according to the pitch of the ore. This latter point is decided by the chief sampler who makes a careful examination of the place to be sampled and if it is an ore body with disseminated ore, the samples are cut horizontally, but if there are a number of veins and large stringers, the samples are cut vertically or at right angles to their dip.

On the other hand, the dissemination of the ore or the stringers might be so complicated that it is found advisable to cut horizontal samples on one side of the drift and vertical ones on the other to get accurate results.
Capote Mine 500 Level
Geological Dept.
C.C.C. Co. July 1, 1915
Scale 1" = 20'

Sketch of Sample Map
A sample consists of the rock obtained from cutting a groove 5' long, 4" wide and 1½" deep. The grooves are cut as neatly and in as straight a line as possible. The cuttings are then sacked, tagged on the inside with the mine, level, drift number, date, geological department, and a number corresponding to the number on the sketch of the drift to show the location of the sample.

The samples are sent to the assay office and in two or three days the results are turned in to the geological office. Then a tracing is made and several blue prints which are sent to the superintendent's office and the foreman of the mine where the sampling occurred.

On the opposite page a sketch of the way in which the sample map is made is shown.
GENERAL INSTRUCTIONS FOR SAMPLERS

When doing any sampling, it should be clearly understood that the regular work in the mine is not to be interfered with. The regular mine work always has the right of way, and when the two conflict, the sampling should be postponed until a more opportune time.

Whenever it becomes necessary to remove lagging, plank or any timber in order to take the sample, all of this material should be replaced after the sample has been taken. Wherever possible, every place should be left in the same condition as found.

The sampler has no authority except over his own men.

The sampler's duties shall consist:

(a) In arranging for the hiring and discharging of his men, and reporting their time to the time office.
(b) In marking out the work of sampling.
(c) In keeping his men supplied with sharp tools, canvas and sacks.
(d) In tagging and locating accurately the position of each sample so that a map can be made in the office without the necessity of additional information.
(e) In providing for the transportation of all samples to the assay office or sampling mill.
(f) In making a monthly report showing the mine, the level, the number of samples both vertical and horizontal, the footage, and cost of samples taken during the month.

He should employ the remainder of his time in preparing the ground for his samplers or in cutting samples with his own men.

He should report any change of ground or any reason which would necessitate a change in the method of sampling.

He should make any suggestion in regard to this work that he considers would increase its accuracy or efficiency.
A COMPARISON OF METHODS & RESULTS OF
MINE SAMPLING.

The following shows the difference between a regular systematic method of sampling and the daily grab sample taken from the breast or the pile of broken ore. The daily grab samples are taken by one of the mine bosses or sometimes by a regular sampler, who makes a regular run visiting every working place in the mine daily. Necessarily the sample is small and must be hurriedly taken.

In the case of the Capote mine, in which this comparison of results is made, the majority of the daily mine samples did not weigh more than 1 lb. each. The samples taken by the geological department consist of the material removed in cutting a horizontal groove 4" wide, 1½" deep, and 5' long, each sample weighing between 50 and 70 lbs. One of these samples is taken for each 5 ft. of the drift. In case of raises, the samples are vertical grooves as well as in the case of a few of the drifts that enter into this comparison. Each comparison represents the same length of drift or block sampled by the two methods.

In general, the material on which these comparisons are made is a sulphide ore with an analysis approximately as follows:

$SiO_2 22\%$, $S 30\%$, $Fe 28\%$, $Al 0.6.5\%$.

The iron, sulphur and copper are combined as pyrite, chalcopyrite and bornite. The alumina is mostly combined as
kaolin while the excess of the silica is nearly all quartz.

The following averages were taken from a block of ground representing an area of 8200 sq.ft. with dimensions roughly 50 ft. by 200 ft.

- **Mine** 79 samples average 6.31% Cu.
- **Geological Dept.** 61 " " 3.90% Cu.

An area which includes the above area alone representing 129950 sq. ft. blocked out in drifts and cross cuts, gave the following results:

- **Mine** 129 samples average 4.93% Cu.
- **Geological Dept.** 97 " " 3.33% Cu.

The average of the raises in this same area, totalling 490 ft. in length, gave the following results:

<table>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5-11-2</td>
<td></td>
<td>26</td>
<td>2.90</td>
<td>10</td>
<td>1.64</td>
<td></td>
</tr>
<tr>
<td>5-11-3</td>
<td></td>
<td>41</td>
<td>3.55</td>
<td>11</td>
<td>5.05</td>
<td></td>
</tr>
<tr>
<td>5-11-4</td>
<td></td>
<td>22</td>
<td>4.36</td>
<td>6</td>
<td>3.61</td>
<td></td>
</tr>
<tr>
<td>5-11-5</td>
<td></td>
<td>9</td>
<td>3.19</td>
<td>3</td>
<td>1.57</td>
<td></td>
</tr>
<tr>
<td>5-35-1</td>
<td></td>
<td>39</td>
<td>3.85</td>
<td>13</td>
<td>3.30</td>
<td></td>
</tr>
<tr>
<td>5-36-1</td>
<td></td>
<td>34</td>
<td>2.93</td>
<td>10</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>5-37-1</td>
<td></td>
<td>21</td>
<td>4.80</td>
<td>4</td>
<td>4.55</td>
<td></td>
</tr>
</tbody>
</table>

The average of a small block of ore 20 by 30 ft. at the junction of two drifts at right angles gave the greatest variation. The ore consisted of very rich bunches and stringers of bornite in a pyrite and quartz gangue. On this ore the sample ran as follows:

| Mine | 22 samples | Geol. Dept. | 10 " |
| Cu.  | 11.5% 12.3 0.04 | Ag. 4.8% 4.6 0.04 |

The lowest mine sample ran 5% copper, the highest 20%, while 14 samples were above 10%. 
The average of 75 ft. of massive low grade pyrite on the 400 level was as follows:

Mine ........................................ 26 samples average 1.40% Cu.
Geological Dept. .............................. 15 " 0.88% Cu.

The following averages of drifts show the relation of samples taken on the 400 level of waste as well as ore.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>424</td>
<td>18</td>
<td>12</td>
<td>4.32</td>
<td>1.65</td>
</tr>
<tr>
<td>426</td>
<td>16</td>
<td>7</td>
<td>2.74</td>
<td>2.33</td>
</tr>
<tr>
<td>427 W</td>
<td>16</td>
<td>9</td>
<td>2.09</td>
<td>1.25</td>
</tr>
<tr>
<td>427 E</td>
<td>11</td>
<td>5</td>
<td>2.94</td>
<td>2.06</td>
</tr>
<tr>
<td>428 E</td>
<td>11</td>
<td>6</td>
<td>7.60</td>
<td>2.26</td>
</tr>
<tr>
<td>428 W</td>
<td>19</td>
<td>11</td>
<td>0.188</td>
<td>0.75</td>
</tr>
<tr>
<td>429 E&amp;W</td>
<td>15</td>
<td>15</td>
<td>3.72</td>
<td>2.50</td>
</tr>
<tr>
<td>409</td>
<td>61</td>
<td>31</td>
<td>4.25</td>
<td>1.93</td>
</tr>
<tr>
<td>409-2</td>
<td>17</td>
<td>3</td>
<td>4.05</td>
<td>3.35</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>3.67</td>
<td>1.88</td>
</tr>
</tbody>
</table>

The final total averages for the 400 and 500 levels, including high and low grade ore, gave the following results:

Mine ........................................ 470 samples average 3.94% Cu.
Geol. Dept. ................................. 244 " 2.64% Cu.

That is, the samples taken by the Geological Department on the average are about two-thirds as high as those taken by the mine bosses.
# MUESTRA DE LOS CARROS

**FECHA:** _______________________ 

**MINA:** _______________________ 

**NIVEL:** _______________________ 

**NUMERO DEL CHUTE:** _______________________ 

**NUMERO DE TRENTE:** _______________________ 

**PESO DE DIA & NOCHE:** _______________________ 

**NUMERO DE CARROS:** _______________________ 

**METAL, PRIMERA & SEGUNDA:** _______________________ 

**NOMBRE DEL MUESTRERO:** _______________________ 

**OBSERVACIONES:** _______________________ 

---

*Mine Sample Tag.*
**CAR SAMPLE REPORT**

Ore mined the 24 hours ending 7 a.m. May 9th, 1914.

| LOCATION | FIRST CLASS | | | SECOND CLASS | | | MISCELLANEOUS | REMARKS |
|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|          | CARS | % CU. | | CARS | % CU. | | | |
|          | Day | Night | Day | Night | Day | Night | |
| 2-51-1   | 15  | 2.2  | | | | | |
| 2-51-2   | 18  | 2.3  | | | | | |
| 2-51-3   | 55  | 1.3  | | | | | |
| 2-51-4   | 25  | 3.0  | | | | | |
| 2-51-5   | 48  | 1.6  | | | | | |
| 2-51-6   | 29  | 2.0  | | | | | |
| 2-51-7   | 17  | 2.2  | | | | | |
| 2-51-8   | 15  | 2.1  | | | | | |
| 2-51-9   | 17  | 2.0  | | | | | |
| 2-51-10  | 16  | 2.0  | | | | | |
| 2-51-11  | 10  | 2.0  | | | | | |
Before closing with the subject of sampling, it is interesting to note how the ore from the mine is sampled and how close the samples check.

Underground, the trammers take a grab sample from each car as they run the ore out of the chute. Beforehand, each chute in the whole mine had been previously numbered in this way. A small board, 12” x 5”, had been painted white and on it the number of the chute or drift stencilled in black paint. The signboard was then nailed to the chute or drift timbers. In this way there is no mistake in marking up the samples. A tally board and a receptacle such as a powder box or sack is placed handy by the chute.

After filling the car from the chute, the trammer takes a grab sample, using both his hands and throws it in the sample box at the same time, tallying his car. At the end of the shift, the shift-boss comes around with a specially made tag, fills it up with the required data, and sends it to the station level to be hoisted to the surface.

The results of the car samples are put on a special sample sheet by the assayer, one sheet to each mine, and copies are sent to the foreman of the mine, superintendent, and geological department. I am enclosing on the opposite sheet, one of the sample tags and sample report as examples, filling the report up with results. Multiplying the number of cars by the corresponding assay will give a number, and adding all these numbers together and dividing the result by the number of cars...
Steel Bins for 1st Class Ore & Conveyor Belt to Sample Mill.

Travelling Tripper Spreading the Ore in Layers on Bed.
Back View of Reclaimer.

The End of the Ore Bed.
for the day, the average assay for the ore for the mine for the whole twenty-four hours preceding will be obtained.

The ore from the chute is hoisted to the surface and a motor train carries it from the large underground bins to the railroad bins. These bins are emptied every day, the first class ore, that is all that above 3% Cu., is taken direct to the smelter bins and the second class to the concentrator. At the smelter each mine has its separate bin, so that as the ore passes through the sample mill, an accurate mechanical sample is taken. The ensuing result is, of course, accurate and on comparing it with the car sample result of the corresponding day, it is found invariably that car sampling by grabs always comes a little high, but on the whole proves to be very satisfactory.

From the sample mill the crushed ore is taken out on a conveyor belt and put on the spreading beds by a travelling tripper, which dumps the different ores and fluxes in layers. Each bed holds about 7,000 tons of ore and, when finished, a reclaimer scrapes the ore, by cutting out a vertical section of the right mixture onto a conveyor belt which in turn carries it to the blast furnaces of the smelter. The accompanying photograph illustrates this well.
UNDERGROUND STOPE MAPPING

The Underground Note-Book. The sheets are made of co-ordinated paper, 10 small squares to the inch or 1" equals 50'. The size of each sheet is 6" x 3½", and there is one sheet to each floor of the stope. The cover of the note book is an I-P Loose-Leaf. The sheets of the different mines are kept separate and taken underground as needed.

The Outfit. (1) Underground note book as described above, (2) 4-H pencil, (3) small protractor, (4) 6" scale, graduated to the scale of 1" equals 50', (5) fifty-foot cloth tape, (6) two pieces of candle and (7) pocket Brunton. This is generally all carried in a knapsack slung over one's shoulder.

Underground Work. When the engineer reaches the mine desired, he descends to the level where the work is to take place, and proceeds to the stope he wishes to map. Let us suppose that the stope he wishes to map is a square set and six floors up or 38' high. As the engineer was presumably present when the stope was started, he naturally has in his note book the map of the sill floor showing the drifts and the location of the raises, also a sketch of the stope as it looked when mined on the sill but now filled in.

He now picks out one of the raises and climbs up five sets, the top of which brings him up to the sixth floor. The intervening floors below, having all been mined out and filled up with waste, he is free to walk about and make his map. He first locates all the other raises and chutes that have been brought up from the sill floor, and the best way to do that is
to place the sixth floor sheet above the sill floor and trace them through. This is correct, provided that none of the raises have been offset coming up to the sixth floor. If they have, due allowance must be made and the offset sketched in on its proper floor.

With the raises accurately located on the 6th floor sheet, it is an easy matter to sketch in an outline of the stope, since it happens to be a square set one, the square sets being 5' apart and each co-ordinate on the sheet representing a square set.

In the case of the slicing method of mining, where each slice is 10' and the work is begun at the top of the ore body, the engineer arranges his notes a little differently. Each sheet represents a 10' slice, numbered from the sill floor up in the following manner: 10' up, 20' up, 30' up, etc. right on up to the level above.

As before, he accurately locates his raises again on the sill floor sheet and carries them on up on each sheet. Then he climbs up to the place where the work is being carried on, let us suppose that it is 50' from the sill floor.

A slicing stope is very irregular and the back is supported by 10' stulls, there being no square sets. This necessitates careful mapping and use of the Brunton instrument and tape. The usual method is to put a lighted candle at the raise up which the engineer has just come, then to place another candle in a convenient corner of the stope, take a sight on it, measure the distance and for accuracy’s sake, take a back sight and use the average reading. He makes several of these shots.
Stope Map, 5th Floor.
to different parts of the stope, plots them in pencil and
with the aid of his protractor, locates the outline of the stope
very accurately.

At the Kirk 9 Mine, where the ore is to be found in a
narrow vein, 3' to 5' wide, and having a dip of about 45 degrees,
more or less, the mapping of the stope is a pretty simple matter.

The drifts on the sill floor would follow the course
of the vein. Raises would be put up about 50' apart, sometimes
less than that, on the incline to follow the vein. It is now
easy to see that the mining generally consists of taking the ore
that lies between the raises. All the engineer has to do in
mapping them is to connect them up. (See sketch)

Sometimes a pocket is encountered and the stope is
square setted so the mapping is as previously described.

In the mapping of stopes, accuracy is the prime factor,
as the maps come under the notice of the mine bosses, foreman,
and all in charge, who would refer to them to locate the best
place to put up a raise or make a connection with some drift
or other part of the mine.

This work gives the engineer a thorough understanding
of mining methods and he acquires besides a very good knowledge
of all the mines, drifts, and raises.

Here follows a set of recommendations given out by the
geological department, which might prove interesting.
RECOMMENDATIONS FOR RECORDING STOPES.

The following recommendations were compiled by the chief geologist at Cananea and were strictly adhered to by all engineers doing this work.

Print every description, name of stope, etc.
Do not write anything on the stope sheets.
Always print parallel to the horizontal line on the stope sheets except in the case of drifts and raises.
Do not ink in any floor until you think it is completed for the present at least. In the case of square set stopes, dot the outside lines of posts with ink when the floor is completed.
In the lower right hand corner of the sheets make descriptions of location of stopes complete.
Do not draw raises or drifts free hand except when underground.
Number raises on each sheet and draw in with ink when in the office.
Do not blacken out or color ground mined or pillars of ore left.
Put a north arrow on every floor and orient each so that raises will be vertically over those on the floor below.
Use abbreviations as per lists.
Leave no pencil marks that mean nothing.
Do not carbon anything for final work. Carbon very light and go over with ink in cases of sill floors and in pencil in other cases.
Use a 4-H pencil for all pencil work and make all lines thin.
In case you wish to record notes on geology, method of mining etc., rule back of sheet and write out any long descriptions,
marking on front of sheet the letters S.E.O. (See note over.)
Make a sheet for each floor of the stope. In the case of slices and open stopes, a floor should be made for each 10 ft. in vertical height. In the case of square sets, one for each floor.
Do not show on one floor a stope with different elevations on it as 10, 15, 35 ft up. Make a separate floor which shows the area of each stope at elevations of 10, 20, 30 ft. up etc. above each level. In the case of the Eureka veins and similar occurrences, make floors as described on separate sheets, making cross sections every 25 ft. to show the exact ore mined. If 25 ft. is not a sufficiently close interval, in special cases place them closer.

"MAKE ACCURACY THE FIRST ENDEAVOR, BUT LET NEATNESS BE A VERY CLOSE SECOND."
MAPPING UNDERGROUND GEOLOGY

Referring to the article headed maps, there will be found a description of the map used underground in this work under the name of "Underground Sheets".

The mine workings, drifts, tunnels, etc., having all been brought up to date in the book, the geologist goes underground with the following outfit: (1) a geology hand-pick strapped to his side, (2) Brunton surveying instrument, (3) a 6" scale, 1" equals 50', (4) note book, pencil etc., (5) carbide lamp.

On going to the drift he wishes to map, he looks over the ground, first so as to get a better idea of what he is going to do; for example, to see if the character of the ground is going to change, say from diorite to limestone, whether prominent faults are present, or if the ground is in ore waste.

Assuming that he has previously plotted the geology of this particular drift to within 200' of the breast, he goes to his starting point and paces off carefully the 200' of ground marking with his carbide lamp on the rock every interval of 25'. He then marks off on his map, for convenience, 10' intervals. All this very much facilitates the mapping of the geology.

The geologist advances very slowly, picking at the ground on both sides of the drift, and whenever he comes across a fault, slip or vein, he sketches it in in pencil in its proper position on the map, showing the dip and the number of degrees, as given by the Brunton.
If he comes to a part of the drift which is timbered and lagged, he marks it to show why there is no geology recorded for that particular length of drift.

Everything at all worthy of note is put in a book and the following are some of the most important: water courses, sheeting and bedding with dip, contacts, kind of ground whether decomposed or altered, pyrite, whether ore or waste, stringers etc.

Following are the geological symbols used in this work and one can readily see how a drift, with complex geology, can look on a map. (See sketch).

GEOLOGICAL SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Copper</td>
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<tr>
<td>Iron oxides</td>
<td>Brown dots</td>
</tr>
<tr>
<td>Iron sulphide</td>
<td>Red dots</td>
</tr>
<tr>
<td>Garnet</td>
<td>Orange dots</td>
</tr>
<tr>
<td>Silica</td>
<td>Yellow dashes</td>
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<tr>
<td>Manganese</td>
<td>Brown circles</td>
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<tr>
<td>Faults</td>
<td>Double black line</td>
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<tr>
<td>Slips</td>
<td>Single black line</td>
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<tr>
<td>Sheeting</td>
<td>Thin black lines</td>
</tr>
<tr>
<td>Bedding</td>
<td>Thin black lines</td>
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<td>Normal contact</td>
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<tr>
<td>Dumps</td>
<td>Fine black dash line</td>
</tr>
<tr>
<td>Open cuts</td>
<td>Black line with hatching</td>
</tr>
<tr>
<td>Wash</td>
<td>Black dashes</td>
</tr>
<tr>
<td>Formations</td>
<td>Pencils as per legend</td>
</tr>
</tbody>
</table>

When the geologist gets back to the office, the first thing he does is to go over the field work, and rub out all the pencil notes after he has neatly printed them in ink. With colored chalk, he fills in the drifts, each color representing a different kind of rock, for example, blue for limestone, yellow
for quartzite and green for diorite. These are the most important formations.

This being done, he transfers the geology from this underground field book to the geology maps proper i.e. the 29" x 30" tracings, a description of which will be found under the chapter "Maps".

This work only includes drifts and tunnels. Only a little attention is given to the geology of stope openings, and that geology when taken, is put on the stope maps and only the important geology at that, such as large veins, strong faults, contacts.

There was very little surface geology to be done at Cananea proper as the Company and geological department possessed complete maps of it made by Mr. S. F. Emmons, of the U. S. Geological Survey in 1908. The geology of some of the outlying claims belonging to the Company had to be mapped, but the method of procedure is the same as what the student has to do in his field work around Rolla, so there is no need to go into details here.
LEASING

During the latter part of my stay in Cananea, the management decided to throw open the surface of all the Company property in and around Cananea to prospectors, Mexicans only.

There was an immediate rush of all classes of men out of work to find a likely piece of ground on which to obtain a lease. They came so fast to the office of the superintendent that all work to do with giving out leases was turned over to the geological department and incidentally myself.

After finding a piece of ground, the Mexican would come to my office at a stated hour and explain where his ground was located. Due to the large number of leases it became necessary to make a regular round to their claims.

After looking at the different locations and before giving the lease, there were several points to consider.

1. Whether the Mexican was a desirable or undesirable man to have working for the Company. Undesirables were the labor agitators.

2. Whether the piece of ground or mine dump, for dumps were included in leases, was likely to run 3% copper or more. Generally before calling me out to see his ground, the Mexican would have put in two or three days' work on his showing, so that I could see what was there. In both cases of dumps and veins, a grab sample would be taken and if they did not run 3% copper at least, no lease was given.
(3) That the leasing on that particular piece of ground would in no way whatsoever interfere with any of the mine workings. This was a most important point as can be readily understood.

(4) That the work would not damage roads, buildings etc.

(5) That before taking the lease over, the Mexican would enter into the following agreement with the Company:

(a) To ship no ore running less than 3% copper. If it was under 3%, after it had already been shipped and sampled, a deduction would be made for every fraction of one percent below three percent. Before a shipment of ore was made, it was my duty to sample the pile thoroughly so as to prevent a low grade shipment.

(b) The lessee would only be paid for copper at the rate of $2.00 Mexican currency, per unit, that is, three percent copper ore would bring in $6.00 per ton. He would not be paid for any silver or gold in the ore. But in the case of a high grade silver lease, provided that the agreement said that the lessee was mining in this case silver and not copper, he would get paid for the silver at the rate of 8 ounces of silver being equivalent to one percent copper. He would also get paid for the copper in his ore but it was very seldom above two percent.

(c) That no shipment could be less than 20 Tons that is, one railroad car load.

(d) The Company had the right to take away the lease after sixty days, unless another agreement for sixty
Method of Sampling Mine Dump.

The method of sampling mine dumps involves collecting representative samples from various parts of the dump. This is important for accurate analysis and understanding the characteristics of the material in the dump. Typically, a grid or sampling plan is established to ensure that samples are taken from different areas of the dump to provide a comprehensive picture of its composition.

For the purpose of this method, it is common to use a sampling tool, such as a shovel or a sampling device designed for mine dumps. The samples are then taken from the designated areas and stored in appropriate containers for further analysis.

This procedure helps in assessing the material's properties, such as texture, density, and composition, which is crucial for mining operations, environmental impact assessments, and regulatory compliance.
days was entered upon, but the Company was under no obligation to renew the lease after the expiration of sixty days.

(e) That the lessee's claim was fixed at 150 ft. in four directions from his original starting point.

Very few Mexicans had anything with which to start the work so a requisition on the store was given them with which he could obtain tools for himself and partner,—such as picks, shovels, hand steel, single and double jacks, wheelbarrow, box of powder and fuse.

Since the lessees could not obtain any money for their ore until it was shipped, weighed and sampled, some method had to be fixed by which the Company could safely advance them money on their ore piles. When a man needed money he came to the office and said he had a car load of ore or more. It was not very difficult to estimate the tonnage and the percentage of his ore, as it was generally high grade, but anything that looked at all doubtful, was thoroughly sampled. If it went over three percent, money to last him until the returns from the smelter came in was given him. If it was below three percent, he could not ship his ore and no money was advanced him, so the lessee generally gave up that location or soon found another.

The shipping of the ore soon became a problem. The leasers, in a short time, had so many car loads ready that the Narrow Gauge Railroad could not cope with the demand, especially since they still had the hauling of the ore from the mines to do. There was also a shortage of cars so the leasers had to
take them in turns. The railroad would not locate any car on the main line but would put it on the spur nearest to the leaser's workings, so it was up to the leaser to pack his ore by burros to the spur before asking for the car. He and his men loaded it themselves, and the railroad hauled it as quickly as possible to the scale and then to the bins outside of the sample mill. This is where the longest delay occurred as it was necessary to have a clean, empty bin for each leaser. As only a limited number of bins were available, the leaser had to await his turn.

The weight of the ore was turned into the office as dry weight, and the percentage of the ore was carried to the second decimal place. The money due the leaser was easily figured out and from it was deducted all requisitions and loans.

The great value of this leasing proposition was that the Company was getting all its surface prospecting done and was getting money for it. The leasers in some cases opened up some very valuable showings, which generally could be reached from one of the mines by driving a raise. In fact, they showed the Company that some localities had a good showing and might open up into a valuable piece of ground and that others were without value.
Almost every method of mining is in use in Cananea and a brief description of each will be given.

Some of the mines had stopes which required no timbering, but as a rule, extensive timbering was found to be necessary. The application of any particular method of supporting the stopes depended upon the dip, the width of ore body, character of the ore and walls, and cost of materials. The following are the methods in Cananea.

1. Square Set Stopes.
2. Filling with broken ore subsequently withdrawn, known as shrinkage stoping.
3. Caving system.
4. Top slicing method.
5. Filling stope with waste.
6. Mining a narrow vein.

Square Set Stopes. This was at one time extensively used and it is still now in use but not as much as formerly due to the high cost of timbering and the lower grade of the ore in the Cananea mines.

The extent and width of the ore body having been determined by drifting and cross cutting every 50 ft., the sill floor is mined out and square setted, and the whole carried up from the sill to the level above. As the work progresses upwards, the lower sets are filled in with waste, but a set on an average of every 25 ft. is left open and is used as a chute to draw off the ore. If the stope itself cannot furnish enough
waste for the filling, plenty is obtained from the development
drifts. Very little waste is hoisted to the surface and dumped
as all of the mines can use it in filling their stopes.

The ore and waste in all stopes is handled with shovels
and wheelbarrows. Tracks and mine cars are not used in the
stopes when once they are mined out above the sill floor.

(2) Shrinkage Stoping. This method is extensively
used at the Cananea-Duluth mine because of the favorable condition
of the ground, namely its hardiness.

This system consists of mining the ore from the sill
floor let us suppose for 200 by 100 ft., leaving a few pillars
to support the roof. During the early stages of stoping, the
ore is drawn off for broken ore occupies from 30% to 40% more
space than ore in place. The whole idea of this method is to
work up from one level to the next filling the stope with the
ore and waste that is broken from overhead, leaving the pillars
intact all the way up. Chutes are carried up and the top kept
level with the surface of the broken ore and through these
chutes all the surplus ore is drawn off for, as mentioned above,
broken rock occupies more space than solid ground. From seven
to ten feet of space is left between the roof and the surface
of broken ground. This leaves sufficient space for the men to
work in.

The broken ore supports the walls of the stope and
also relieves the pillars of some of the strain. All loose rock
overhead is barred down before the men begin to drill.

When the stope is worked out, the broken ore is drawn
off at the bottom and this leaves a large cavity supported by pillars. These pillars in turn are shot down and the ore drawn off.

There are now in the Cananea-Duluth mine on the upper levels, large open stopes without any pillars whatsoever, which have stood for years, some as high as 200 ft. This shows that in regard to the nature of the ground, this method is safe and justifiable.

(3) The Caving System. This is not used in Cananea to a very great extent except on the upper level of the Veta Grande Mine. The top slicing method, which is a variation of the caving system, will be described later. This method is used very extensively in all of the mines and found to be a very cheap method of mining.

The top of the ore in this particular part of the Veta Grande Mine came up as close as 30 ft. to the surface in some parts, leaving a matt or overburden varying in thickness from 30 to 100 ft. Drifts and cross cuts were driven in the ore to its limits and then the ore was mined from the fartherest point in back to the shaft. The roof was supported by a few stulls and in a few places by a square set or two but otherwise very little timber was used. As the miners worked back, the matt or overburden was allowed to settle so that when all the ore was taken out the surface only the hillside had settled a few feet. The above was repeated ten feet down and the ground settled again into the space formerly occupied by the ore. When the whole ore body had been taken out to a depth of 100 ft., the surface of the hill had settled approximately that distance.
A good photograph of the effect on the surface of the ground by that method is shown.

(4) Top Slicing Method. As the name indicates the extraction is begun at the top of the ore body. This method, as previously stated, is a variation of the sawing system except for the fact that a great deal more timber is used and the timber acts as a mat to support the roof.

Supposing the slicing to be done is on an ore body between the 300 and 200 levels and is not larger than 50 by 75 ft. A raise or maybe two are first driven up from the 300 to 200 level on the edge of the ore. Then starting at ten feet below the 200 sill, a ten foot slice is taken out as follows; A drift is driven through the middle of the ore body and then it is cross cutted. The mining is begun at the end fartherest away from the raise and chute, and the extraction of the ore is carried on backwards towards the chute, timbering the ground with ten foot stulls as the work progresses. In time there is an open space 50 by 75 feet, held up by stulls and all the timber in turn is shot, thus letting the heavy ground above down all at once to the floor. The stulls in falling form a mat so that in coming under it for the next ten foot is slice, that is 20 feet below the 200 level, the ground is supported by means of stulls again. This is repeated ten times, or as many times as is required to mine the 100 foot of ore.

Now in the case of a larger ore body, the same procedure is followed out but with this difference, that instead of having an open ten foot slice of large dimensions supported by stulls and letting it all down at once, the ground overhead or mat as
the case would be, is let down as the miners work back. In this way the great weight overhead is in part relieved.

In some cases it is found advisable to put down a board floor of ten foot planks, so that it makes a good and uniform mat by which to support the overburden when coming under with the next ten foot slice. This is not often done as it is much too expensive.

(6) Another method of mining employed in good hard ground, is to fill up the stope with waste and support the roof with a few sets of cribbing. This system is the same as the square set method except that there are no square sets but only cribbing.

The excavation is begun on the sill floor and all the space is filled in with waste either from the stope itself or from other parts of the mine, up to within seven or ten feet of the roof. Cribbing is placed here and there to support the roof and the chutes are carried up with the stope as the work progresses.

As one part of the stope becomes filled up with waste, the cribbing is removed, and the ore overhead is taken out for a height of about fifteen feet and the space then cribbed. Then the other half of the stope is treated in the same way and so on. Thus, the same cribbing is used over and over again, making the cost of timbering for that stope very low.

(6) Mining of Veins. Before closing this subject, a few words about veins and their methods of mining would not be amiss.

There are two important vein mines in Cananea,- The Kirk 9
and the Eureka Mines.

Both these veins dip about 45 degrees and are in limestone with this difference, namely, the Eureka vein is in a hard marbleized limestone while the Kirk 9 is in a soft, ferruginous limestone, much garnetized and decomposed.

In the Eureka, the miners go up on the vein filling the open space with waste, here and there putting in a few stalls but there is no timbering worth mentioning.

In the Kirk 9 as in the Eureka, the work of extraction begins at the sill of one level and goes up to the sill of the level above, the raises following the dip of the vein. In the narrow sections of the vein, the ground is heavily stulled and of course filled in with waste. In the wider parts, square sets are put up and the sides generally well lagged.
Topography. The Cananea range present the general form characteristic of the so-called Basis ranges. Namely, it is a steep ridge or series of ridges rising out of broad, gently sloping valley plains, and represents the projecting summits of an older and probably much wider mountain uplift, now partly buried beneath gravels and silt that have accumulated during Quaternary time to a depth sometimes of several thousand feet in the lower parts of the surrounding valleys.

This range differs from the Basis range of Arizona or Nevada in the fact that its slopes are clothed with abundant vegetation and, at one time, coniferous trees. These indicate an abundant precipitation for this arid region, due to the superior height of the mountain mass.

This range is made up of several individual ridges which have a northwest-southeast trend, though the average direction of the whole range is north and south.

The mountains are drained, on the east by the Puertecitos and San Pedro creeks, north into the Gila river and south into the Sonora river.

Sketch of Geological History. The Cananea mountains are made up to so great an extent of eruptive rocks that it is difficult to decipher their geological history. The few sedimentary beds that occur there are quite barren of any
recognizable remains of ancient life, from which the ages of rocks are determined. Therefore, analogy and lithological resemblances of the nearest known district i.e. Bisbee must be depended upon.

**Pre-Cretaceous Sediments.** The only distinctly sedimentary beds in Cananea are the quartzite and overlying limestones, and these, with reasonable certainty, are assumed to be of Cambrian age, corresponding to the Bolsa quartzite and Abrigo limestones of the Bisbee district. Hence, the older granite complex, upon which the former rests, must be of Pre-Cambrian age.

As to the eruptive rocks, extrusive as well as intrusive, analogy again tells us that they are of Post-Cretaceous or Tertiary time. This was the period of greatest volcanic activity both in Mexico and U. S. A. The eruptive rocks of Arizona and New Mexico, which are similar to those at Cananea, are known to be of that age.

Between Cambrian and Tertiary time, there probably was a mountain uplift that raised this region above the surrounding country in Pre-Cretaceous time.

There is no evidence on the mountain slopes that this range was ever entirely submerged, though sediments were deposited over pre-existing rock surfaces by Cretaceous seas.
Abriqo (Cambrian) Banded Limestone.
Post-Cretaceous Igneous Rocks.

<table>
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<td>Cambrian</td>
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<tr>
<td>El Torre syenite</td>
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<td></td>
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<tr>
<td>Elisa quartz-porphyry</td>
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<tr>
<td>Gabbro</td>
<td></td>
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<tr>
<td>Later diabase dikes</td>
<td></td>
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<tr>
<td>Alluvium and wash</td>
<td>Quaternary</td>
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</table>

Successive phases of eruptive action.

1. First intrusion.

Diabase consisting of plagioclase felspar, pyroxene, and magnetite, in whose coarse-grained granular phases the long lath-shaped felspar crystals stand out.

This rock in Mariquita mountain, with smaller outcrops on Elenita. It shows evidence of mineralization in its frequent impregnation with pyrite.

The Mesa tuffs rest directly on this diabase.
2. **Huacolote rhyolite.** More acid than No. 1, and bears the same age relation.

3. **Mesatuffs.** These consist in part of a fine dust of shattered crystals, but in great measure of a breccia of coarser or finer grain, composed of fragments of the underlying rock i.e. diabase. The tuffs do not prove ore bearing.

4. There were also surface flows of lava, which are now found as sheets of andesite. Closely associated with the tuffs are exposures of syenite and syenite-porphyry.

5. The most important intrusion of the region i.e. the Henrietta diorite-porphyry, came after the close of the eruption of the tuffs. This intrusion was the cause of the greater part of the contact metamorphism and mineralization. All the important ore bodies are closely associated with this rock, and the limestone is always garnetized in its vicinity. The rock, when fresh, is dark and rather fine grained, made up of felspar, hornblende and biotite, with occasional quartz. When weathered, it is of a rather light color, often bleached and all structure has disappeared, but generally careful search will reveal some original felspar crystals.

6. **Cuitaca granite or grano-diorite.** A more acid magma which followed the diorite intrusion. In general, this granite shows little mineralization but at Puertecitos it carries some ore bodies near the contact with the limestone.
7. **Tinaja Granite-porphyry** differs only in texture from No. 6. It shows no evidence of mineralization.

8. **Elisa quartz-monzonite-porphyry.** This differs only from Nos. 6 and 7 in possessing a porphyritic rather than granular texture. It carries rounded grains of quartz about the size of a duck shot. It is often impregnated with pyrite whose oxidation imparts a marked red color to its weathered surface. This rock is considered the youngest of the important eruptive rocks of this region.

9. The remaining rocks are the gabbros and the later diabase dikes, which are plagioclase-pyroxene rocks containing magnetite.

**The Gabbros.** Texture granitoid, darker than the ordinary granite. Found cutting the diorite.

**Diabase dikes.** Fine grained texture resembling basalts. Neither of these two rocks have exercised much influence on the ore deposition.

In summing up the above, the succession of alternately more or less basic eruptions would stand in this order:

1. Mariquita  
   Oldest.
2. Huacote
3. Mesa tuffs--- San Pedro
4. El Torre --- Elenita
5. Henrietta
6. Tinaja --- Cuitaca --- Elisa
7. Gabbro --- Diabase  
   Youngest.

After the close of the eruptive period, came a time
Cross Fault at Eliza Hill.

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Quartzite</td>
<td>Limestone</td>
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The image illustrates a geological cross section showing the transition from Quartzite to Limestone at Eliza Hill.
of practically continuous erosion, during which the detrital material was gradually spread out upon the surrounding plains. In one spot, ten miles north of Cananea, the detrital material is known to be 1600 ft. thick, hence this erosion must have continued for a very long time.

The following rock formations, which could not be described and classed in the above eruptive rocks, can be easily recognized from the following data.

Cananea granite. Oldest rock in the district, because it forms the basement upon which the oldest sediments, the Capote quartzite, were deposited. It is a coarse, microline granite with prominent quartzes, and occasional mica now altered to chlorite. The felspar crystals are large, up to an inch. Occasionally occurs as fine grained, its groundness consisting of quartz as small rounded grains, and orthoclase.

Capote quartzite. Uniformly granular as pure quartzite, brownish on weathered surface but almost invariably white underground.

Puertecitos limestone. This overlies the Capote quartzite. It is fine grained, nearly black, very dense and like an argillite. In a good many places it is changed to garnet, which is of a greenish-brown color and of a somewhat greasy lustre.
CONTACT MINERALS.

Contact metamorphic deposits are characterized by the associations of oxides of iron, such as magnetite and specularite, with sulphides of copper, lead, zinc etc.

At the elevated temperature, the solutions were in a gaseous state and penetrated the rock, exchanging its carbonic for silicic acid and depositing their load of metasomatic replacement. The deposits thus formed are not necessarily at the immediate contact of the two rocks, but may have penetrated several hundred feet into the adjoining country rocks.

The metamorphic lime silicate minerals are:

1. Garnet
2. Vesuvianite
3. Wollastonite
4. Epidote
5. Pyroxene
6. Amphibole

The most common of these in Cananea are garnet and epidote. Both are found as contact alteration products of limestone.

Sericite is found as a common alteration product of igneous rocks and quartzite but is not a contact metamorphic mineral.

Magnetite and specularite occur in limestone deposits and rarely seen in igneous rocks.

Hedenbergite which is a variety of pyroxene is also found near the contact of limestone and intrusives.
Quartz and calcite are uniformly present in all types of deposits.

Bornite and chalcopyrite predominate in contact deposits in limestone with subordinate zinc blende, pyrite and galena.

In porphyry deposits, pyrite is predominant with chalcocite as a secondary deposit on the pyrite. Bornite has not been observed. Zinc blende and galena are present in small amounts and tetrahedrite is sometimes found.

Garnet (probably andradite), when fresh is of a greenish-yellow color and somewhat greasy lustre. The rock mass, which it forms, is very hard and tough; and when altered, it decomposes to silica and limonite, which on the surface may be taken for gossan. Underground, it is difficult to distinguish it from other altered rocks, but its slight effervescence with dilute acid is a characteristic.
ORE DEPOSITS.

Contact Metamorphic Deposits.

Definition. In Cananea the contact metamorphic deposits are those in and adjacent to limestone at its contact with intrusive rocks.

The two principal areas are in the limestone belt south of Puertecitos and in that extending southeastward from the Elisa mine.

Puertecitos. The limestone body lies between the grano-diorite and diorite porphyry, both of which have acted as metamorphosing agents. The primary ore minerals are bornite and chalcopyrite.

Important ore bodies are also found in the adjoining igneous rock, which have the characteristics of contact metamorphic deposits, though the lime silicate minerals, as garnet etc., are wanting. In these, the prominent primary copper mineral is chalcopyrite.

Elisa Mine. The ore here occurs mainly as chalcopyrite, with zinc blende and pyrite in a gangue of garnet. It occurs in isolated, rather longitudinal bodies in a zone of limestone, parallel to the Elisa fault. Considerable areas of the limestone are marbleized, but where ore is found, garnet is generally present.

The Elisa fault, with a displacement of a thousand
Elisa Fault on Surface.
feet, is the only great structural fault that can be traced on the surface for any great distance.

Eureka Tunnel and Sierra de Cobre Mine. The ore is in limestone and is like the ordinary contact ore in consisting of rich patches of bornite and chalcopyrite and, being near the present surface, is partly oxidized.

Democrata Mine. This is a small independent mine situated in the midst of the Cananea Cons. Copper Co.'s properties and yet not owned by them. It is one of the richest mines in the district.

The deposits here occur within the partly marble-ized and garnetized limestone under a cover of diorite por-
phyry. The main ore body occurs along a strong fracture zone accompanied by considerable brecciation of the garnet rock.

The greater part of the ore as mined consists of chalcopyrite, bornite, pyrite and zinc blende, with a good deal of quartz and some calcite as gangue minerals.

West Cobre Grande Mine. The deposits of this mine occur in a body of marbleized and garnetized limestone, over-lain on the north by diorite porphyry. On the first level the ore is pyrite, chalcopyrite and zinc blende, and is apparently a contact metamorphic deposit in limestone.

West Cananea Mine. Typical contact metamorphic ore is found here. It occurs in several isolated bodies, within a short distance of the contact of the limestone with an overlying granitoid diorite.
DEPOSITS ON IGNEOUS CONTACTS.

Henrietta Mine. The important ore deposits here are found at or near the contact between diorite-porphyry and quartz-porphyry.

The primary ore is bleached and silicified diorite-porphyry impregnated or partially replaced by grains of pyrite, chalcopyrite and zinc blende. The richer ore occurs in breccia zones or on fault slips and is apparently the result of later concentration or of actual addition of material by later ore-bearing solutions.

While this ore is very irregular and patchy in its mode of occurrence, it has a tendency to follow fault slips or zones of brecciation.

Cobre Grande Mine. Its ores have been deposited in a fracture zone which is rather intermittently ore-bearing. The primary ores are pyrite with a little chalcopyrite.

The normal country rock is the altered and bleached diorite-porphyry, but garnetized limestone is often near-by in the footwall country.

America Mine. There are two systems of fracture about 75 ft. apart, one being entirely in diorite-porphyry, the other having garnet on the footwall and diorite on the hanging. The ore is pyrite and chalcopyrite enriched by chalcocite.
Cananea Central or Bonanza Mine. The deposits have been formed by ore-bearing solutions rising along a set of fissures. The main ore zone is about one hundred feet wide, in which the ore has tended to concentrate along the outer limits.

The primary ore is a cupriferous pyrite, or an admixture of pyrite and chalcopyrite, of very low percentage in copper.

Cananea-Duluth Mine. The deposits occur in an oblong area of diorite-porphyry intruded through Mesa tuffs, far away from any known body of limestone.

In the upper levels, the disseminated ore is a low grade pyritic ore enriched by a chalcocite coating. But along the breccia zones, especially in depth, it consists of pyrite and chalcopyrite with tetrahedrite, the latter mineral producing an increase of the silver values. These minerals, together with a crystalline quartz, often form the entire cement between the porphyry fragments, which are themselves impregnated with pyrite this indicating two periods of mineralization.
CAPOTE BASIN.

This area is distinctly different, both in its geological structure and in the character of its ore deposits, from any other part of the range. It is here that the two richest mines of the district, namely the Capote and Oversight mines, have been developed.

Geological structure. The basin consists of north-easterly dipping limestones resting on quartzites, bounded on all sides, north, east and south, by diorite intrusions and on the west by the uplifted mass of basal granite of Chivapeak, on which the quartzites and limestones rest.

The sedimentary beds have been cut through and split up, and the limestones highly metamorphosed by diorite intrusions, which themselves have been traversed at various points by quartz-porphyry intrusions.

Both diorites and sedimentary beds have been profoundly faulted and shattered.

The diorite intrusions through the center of the basin have the general form of tongues projecting into the limestone.

The Capote Fault. The best defined portion of the fault is that seen in the Capote and Oversight ground. Here the quartzite and limestone beds have a persistent dip of 25° to 50° to the north east. At the Capote Pass, running
north east, is a zone of faulting, much steeper than the bedding, that cuts through limestone and intruding diorite bodies into the underlying quartzite. The displacement has been a downthrow to the east.

The Ricketts fault. It is located a thousand feet east of the Capote fault. The displacement on this fault was an upthrow to the east, which has resulted in bringing up the Capote quartzite in narrow bands to the surface.

It is within this fault block that the great Capote and Oversight ore shoots were found, the one along the Capote and the other along the general line of the Ricketts fault.
Capote Ore Bins.
DISTRIBUTION OF ORE BODIES.

The primary ores of the productive shoots of the Capote Basin are pyrite with small amounts of chalcopyrite, associated in places with zinc blende. Very large areas of faulted rocks are impregnated with these minerals, but along certain lines of marked fracturing they have concentrated into workable ore bodies.

The main ore bodies are found in diorite-porphyry and to a lesser extent in quartzite. The ores of this type are supposedly the result of a later phase of ore deposition than the contact metamorphic type, and to have been formed by hot aqueous solutions emanating from deeper portions of the consolidating magma, which have ascended along channels of most ready circulation.

Capote ore body. This has been the richest and most productive in the Basin. It has now been in a state of combustion on the upper levels for a number of years.

The gossan, covering this ore body, caps not only the quartzite and porphyry along the outcrop of the Capote fault zone, but also the hanging wall limestone for a great width, and in places carries 50% iron.

The main ore chimney stood nearly vertical, decreasing from a length of 475' on the first level to 130' on the fourth, and a second of smaller dimensions starts a little to
Veta Grande and Oversight Ore Bins.
the north and west and has been followed down to the 1000' level.

The ore chimneys lie in brecciated and altered porphyry at or near the Capote fault, which dips steeply northeast over a footwall of quartzite, that is sericitized and impregnated with pyrite. On the east is limestone, cut here and there by porphyry. At the sixth or seventh level, the ore body passes into a breccia made of fragments both of quartzite and porphyry, and the limestone to the east is succeeded by quartzite.

Oversight ore body. There is no gossan above this ore body, the surface consisting of highly silicified fine-grained diorite-porphyry, but slightly iron-stained. So great has been the mass of ore taken from this mine that the whole northeast slope back of it is slipping bodily downward, leaving a fresh vertical wall at the summit of the ridge where it has broken off from the mass of the mountain.

The ore shoot occupied a tongue of crushed diorite protruding into the limestone. The ore was similar mineralogically to the Capote ore, but its mass was less concentrated, consisting rather of a series of lenticular bodies of richer ore with low grade ore between. The country rock is highly sericitized.

The richer portion of the body was 200' below the surface, its extent horizontally being over a 1000' and is bounded on the east by quartzite and on the west by limestone. The great value of this ore body, like all the others lie in the secondary enrichment by chalcocite.
Esperanza ore body. It is separated from the Oversight ore body by a band of quartzite intruded by diorite-porphyry. This ore resembles the Oversight both in composition and structure, but is smaller in size and of still more irregular outline.

Veta Grande ore body. This lies in a tongue of diorite that protrudes into the limestone. The ore of this body follows a zone of intense fracturing and brecciation in this diorite. The highest point of the ore body was known as the Hassey and consisted of rich carbonates with cuprite reduced to native copper.

From the Hassey body downwards in a southeasterly direction the ore has been traced continually down to the 500' level, with constantly decreasing area and percentage of copper. In middle depths it was enriched by chalcocite.

Kirk ore body. The country rock is prevalingly diorite with a little garnet. Underground the garnet areas increase in size.

The diorite underground is both of the fine and coarse grained types. The ground is traversed by many fissures and fracture zones.

Rich carbonate and oxide ores occur in the upper levels, passing into the enriched sulphide below, with primary chalcopyrite, pyrite and zinc blende at still lower levels. The ores are rather irregularly distributed, generally on fracture zones and of relatively high grade in copper.
CONCLUSIONS.

Source of the metals. The successive intrusions of magmas, which have broken through the sedimentary complex, that constituted the original mountain uplift of the region, may be considered to have come from a common deep-seated reservoir, since the eruptive rocks into which these magmas have consolidated display a common relationship to each other. The important feature of this relationship is the evidence that all the magmas were exceptionally rich in the metals, especially iron and copper.

The evidence consists of:

(1) In the widespread impregnation of the various rocks along certain zones by metallic sulphides.

(2) In the fact that different varieties of rocks, far removed from any known ore deposit, all contain a notable percentage of copper.

(3) That wherever the limestones have suffered contact metamorphism by the intrusions of igneous magmas, concentrations of copper ore are almost universally found scattered irregularly through them.

Processes of ore deposition. When an igneous magma first invades a limestone or other sedimentary rock, it is at a very high temperature and under enormous pressure. In contact with the cold invaded rock its temperature is
lowered, and a process of consolidation and crystallization goes on from the contact inward; those materials, which under these conditions are the less fusible, being necessarily the first to consolidate. As crystallization of these materials takes place, the vapor of water and such metallic salts as it may take up in solution separate out and are forced through the interstices of the consolidating and contracting outer crust into the surrounding sedimentary rocks, where they form replacement deposits.

The replacement deposits are as a rule very irregular in form and distribution, because, on account of their gaseous state and high temperature and pressure, the solutions can force their way into rock without awaiting the formation of fissures and other open channels. As time goes on the cooling and consolidation progresses inwards, and, as in the change from a fused to a crystalline condition most rock magmas contract, through this contraction the already consolidated outer portion becomes cracked and fissured.

The aqueous vapors, on the other hand, that are forced out by crystallization, as they come from a deeper source and consequently have a longer distance to traverse, gradually become cooler assuming a liquid form. Until the supply of metals in the magma has been exhausted they continue to bring up the metallic minerals, possibly in less concentrated solutions, which they may deposit in the recently consolidated igneous rocks as well as in the surrounding sedimentaries.
The process of ore deposition by these waters thus passes from the contact metamorphic to the aquaeo-igneous or hydro-thermal phase by gradual transition rather than by any strongly marked change in conditions.

A further progress may be conceived when these hot magmatic and probably highly concentrated solutions meet and mingle with meteoric waters. The resulting and more dilute solutions, rising towards the surface along trunk channels, produce the ordinary or hydro-genic type of vein deposit.

**Mineral associations.** The important characteristic is the association of the metallic minerals with the lime silicates, the most common of which are here garnet, epidote and pyroxene.

Wollastonite (calcium silicate) has also been observed.

Most common primary sulphides are bornite, chalco-pyrite, pyrite and zinc blende. A little galena is also present but magnetite and specularite are rather rare.

Garnet is the most widespread of all the minerals, often replacing such large masses of the limestone as to constitute a rock type, whence it has come to be termed garnet rock.

In the non-limestone or *porphyry-ores*, bornite is unknown as a primary mineral but pyrite is very predominant. Zinc blende occurs both in limestone and porphyry equally, but galena is more predominant in the latter. Tetrahedrite is not uncommon in the richer portions of the porphyry ores. Sericite
is a common alteration product in the country rock of the porphyry ores. Among gangue minerals epidote occurs but no garnet.

Both types of deposits i.e. contact metamorphic and porphyry, have been formed by magmatic waters emanating from cooling igneous magmas, but the porphyry ores have been formed the later of the two, at a time when the ore bearing solutions though still hot were no longer above the critical temperature. These solutions had an increasingly greater distance to travel before precipitation, hence the resulting porphyry ore deposits would therefore depend upon the channels that they followed.

Structural relations of the deposits. The ores in limestone are much less dependent on rock fracture faults than those in porphyry.

At Puertecitos the contacts of limestone with igneous rocks are fault contacts, the ore bodies having followed fracture planes parallel to these contacts.

The ores in porphyry are so closely connected with the faulting and fracturing that the amount and value of the deposits are proportional to the extent of the rock fracturing.

Capote Basin, the location of the greatest ore bodies in Cananea, has been the scene of the most complicated faulting and most intense rock crushing in the district. This area was originally completed covered by limestone beds, then they were split apart by several tongue-like masses of diorite. Subsequently, there was an intrusion of quartz-porphyry followed by a rather irregular system of faulting.
Zones of brecciation along the fault themselves have furnished channels of ready access for the uprising mineral-bearing solutions, which have deposited metallic sulphides as a cement to the breccia, as veinlets along the joint planes and finally as disseminated crystals in the adjoining country rock. The ore here has been deposited rather in the porphyry than in the enclosing sedimentary beds.

The faulting is in places along a single plane and again along a series of parallel planes. The ore solutions ascending along the fissure cracks have replaced the immediate walls of the fissure with ore, impregnating the adjoining country rock and in some places spreading out along nearly flat fissures not far below the present surface.

Secondary enrichment. The alteration of the original ore deposits by waters descending from the surface, their oxidation, leaching down and redeposition as oxides, silicates or carbonates in the oxide zone, or as sulphides in the sulphide zone immediately beneath, have been most important elements in producing the commercially valuable ore of Cananea.

The relative amount of the enrichment depends upon two factors; firstly, the amount of original ore-bearing material which has been removed by erosion, and secondly, the amount and extent of fracturing that has taken place since the original ore deposition.

At Cananea, due to the free circulation of surface waters, the copper and zinc compounds should be completed
removed from the immediate surface, and the iron in the form of an oxide or gossan left behind.

Areas for future exploration. In prospecting for new ore bodies in porphyry areas, besides the evidence of gossan or copper stain at the surface, the prospector should not neglect a fissuring or sheeting of the country rock, especially when accompanied by brecciation.

Silicification is an almost universal accompaniment of ore deposition.

Kaolinization also common and is due to descending surface waters. Kaolin is dead white in color.

Sericitization also common and is formed by the action of hot ascending and in general mineral-bearing waters. Sericite is a white hydrous mica and constitutes a lustrous talcose coating on the rock.

Among areas distinctly unfavorable for prospecting, is the large area occupied by the Cananea granite. There are no intrusions of eruptive rock and no evidence of hydro-thermal action.

Similarly barren is the grano-diorite in Cuitaca basin and in the Tinaja-Huacolote basin, as the diorite in the latter is mostly granitoid and not fine-grained, which is the one associated with known ore bodies.

The Mariquita mountain is not promising either as it is mostly made up of coarsely crystalline diabase. A few prospectors have opened up a small number of stringers of high grade copper-gold-silver ore but there are no
mines operating in that district.

The Mesa tuffs are also barren, though in the Cananea-Duluth mine it is closely associated with the ore bodies.

The Contact Belt, that is the contact that the limestone makes with the diorite-porphyry and the granodiorite, stretching southeastward from Puertecitos is the most promising area for the discovery of large bodies of ore.

In the Elisa mine, it seems advisable to follow the general direction of the Elisa fault, cross-cutting at intervals into the diorite-porphyry in search of a zone of fracturing that prove ore-bearing, if followed downward.

On the last page of this thesis will be found a geological map in colors of the Cananea district. By its aid, all the formations, mines and locations can easily be found besides giving the reader a clearer conception of the geology.