ORIGIN AND TREATMENT OF UNDERGROUND WATERS FROM CERRO DE PASCO MINE, PERU

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ABSTRACT

The Cerro de Pasco mine is one of the most complex run by Centromin Peru S.A. in Central Peru. Underground and open pit mining for Lead-Zinc-Silver and in-situ leaching as well as dump leaching are being carried out over bordering areas. The many operations involved pose complex technological and operational problems.

The geological and hydrogeological characteristics of the deposit are discussed in relation to the origins of the mine water. Around 5,800 GPM of alkaline waters and acid solutions are collected at the mine, at different levels the lowest being 2100 feet below surface. The acid solutions containing copper and iron-sulphur bacteria are used as leachants at the in-situ and dump leaching operations, giving a total of 3,200 GPM of pregnant copper solutions, being finally treated at a SX-EW Plant, whose output is 5,000 Tns/yr of refined copper cathodes.

The in-situ leaching is over an old mine which was worked more than 30 years ago.

It is important to take out the water from the mine to avoid flooding it.

INTRODUCTION

The mineral deposit of Cerro de Pasco is located in the central part of Perú, 180 kilometers Northeast of the city of Lima (Fig. N° 1), at an altitude of 4,330 meters above sea level. Its geographical coordinates are:

10°42' South Latitude
76°15' West Longitude

Undoubtedly, the exploitation of this deposit contributes economically to the development of the highlands of Perú. Its labor force consists of 3,200 workers who produce 186,000 dry short tons of lead, zinc, and silver minerals monthly. The population of Cerro de Pasco (about 23,000 habitants) depends directly or indirectly on the exploitation of these mineral resources.

GEOLOGICAL SETTING

Sedimentary and igneous rocks are in the Cerro de Pasco area. The Sedimentary rocks go from the lower Paleozoic age up to the Cuaternary age, while

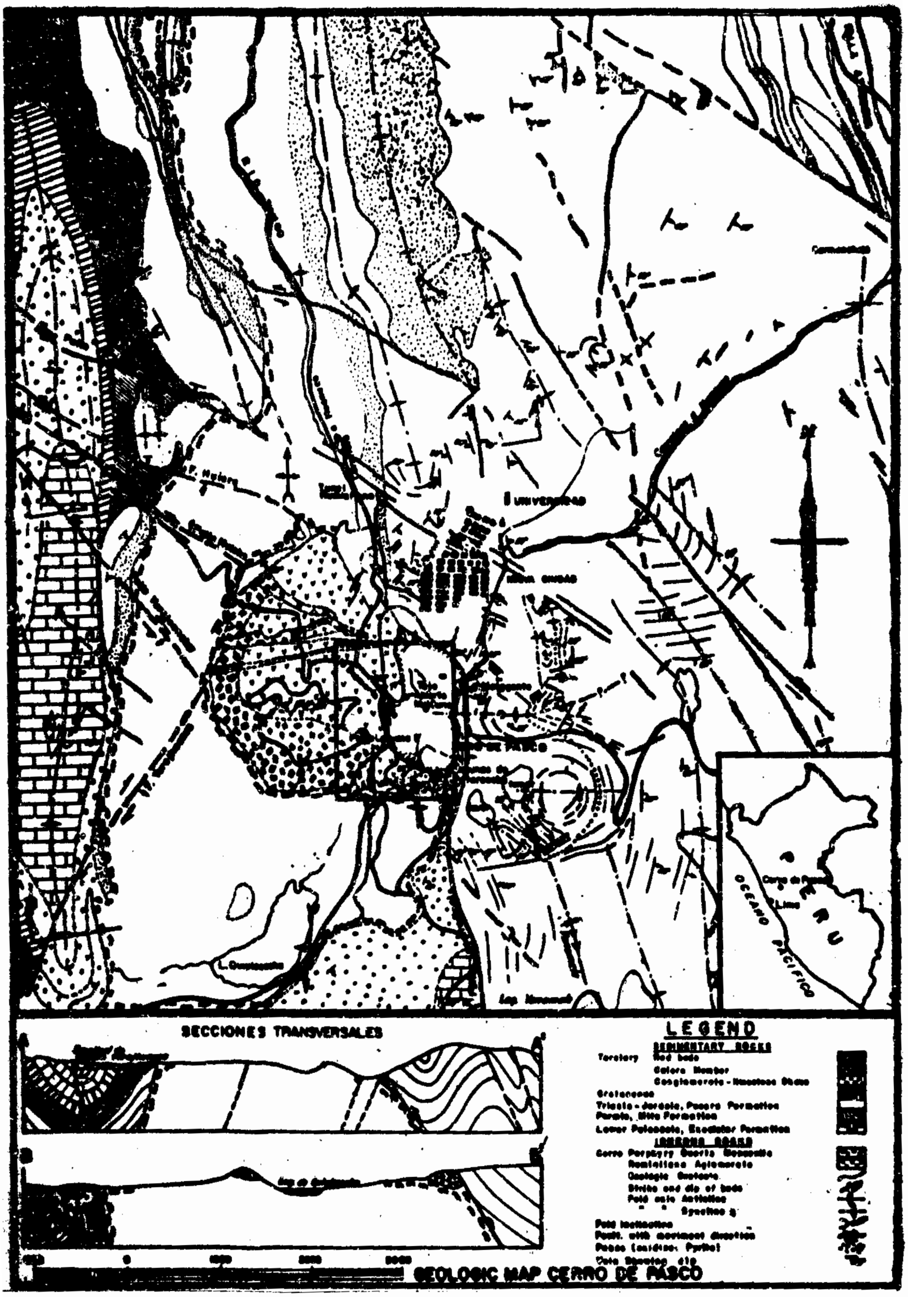
SECCIONES TRANSVERSALES
LEGEND
GEOLOGIC MAP CERRO DE PASCO
OCEANO PACIFICO

FIGURE 1

the igneous activity is Tertiary in age. The latter is of two types: explosive and intrusive.

a).- Rocks.-

We shall only describe the involucred rocks: Siluric-Devonic, (Excelsior Group), made up mainly of phyllites; Triassic-Jurassic, (Pucara Group), made up of thin and thick calcareous beds and shales. Sedimentary rocks were intruded by the igneous activity forming a volcanic vent; Rumiallana Aglomerate is the oldest igneous activity and in contact with the pyrite body it has kaolinization, propylitization, pyritization and a minor scale of sericitization; Porphyry Quartz Monzonite has intruded the vent in irregular masses which transforms the Rumiallana Aglomerate, upon contact, into a cooling marginal breccia called Lourdes fragmental. The quartz monzonite has a light gray color, with a porphyry texture and contains quartz, plagioclases and biotite phenocrysts. The matrix is made up of 0.02 to 0.10 mm of quartz, orthoclase, and oligoclase crystals. Near mineralized zones these were strongly sericitized.

b).- Folding.-

In general, this district is characterized by showing parallel folds which trend northward and which axial planes are dipping eastward. In Pucara limestones, placed immediately at the east from the longitudinal fault, there are minor crossed foldings which axial planes trend eastward and dip northward.

c).- Fracturing.-

There are 6 stages of pre-mineral fracturing and 2 stages of post-mineral fracturing. The main stages related with this paper are: Longitudinal thrust faults; these are parallel to the regional folding and dip 60° to 65° E. They are older than vent; Fractures crossing the west contact of the silica-pyrite body; they are convergent at depth and were mineralized with pyrite-enargite.

MINERALIZATION

The silica-pyrite body is at the eastern margin of the vent. It is 1,800 meters x 300 meters and has pyrrotite pipes and irregular bodies of ore mineral. The silica-pyrite body has an Iron-Silica ratio of about 1:1. It is itself a huge low-grade copper-lead-zinc-silver deposit. Lead-zinc mineral are distributed mainly in the eastern and southern margins of the silica-pyrite body. Veins as well as hypogene copper-silver mineralized bodies are placed in southern and eastern margins of the vent. Copper mineralized bodies are located at the eastern ends of copper veins. Veins, which number more than 150, are distributed in two systems: one which dips northward and another which dips southward (Fig. N° 2).

It is supposed that the copper-silver economic mineralization goes below the 2,700 level (personal communication). In the central area, veins are esentially made up of enargite and pyrite. Both of them are intimately associated in space and time. The tennantite-tetrahedrite is, after enargite, the most abundant mineral and has more arsenic than antimony. In some areas, the sphalerite is replaced by enargite. Marcasite, in small amounts, is broadly distributed along veins. Other copper minerals (chalco-

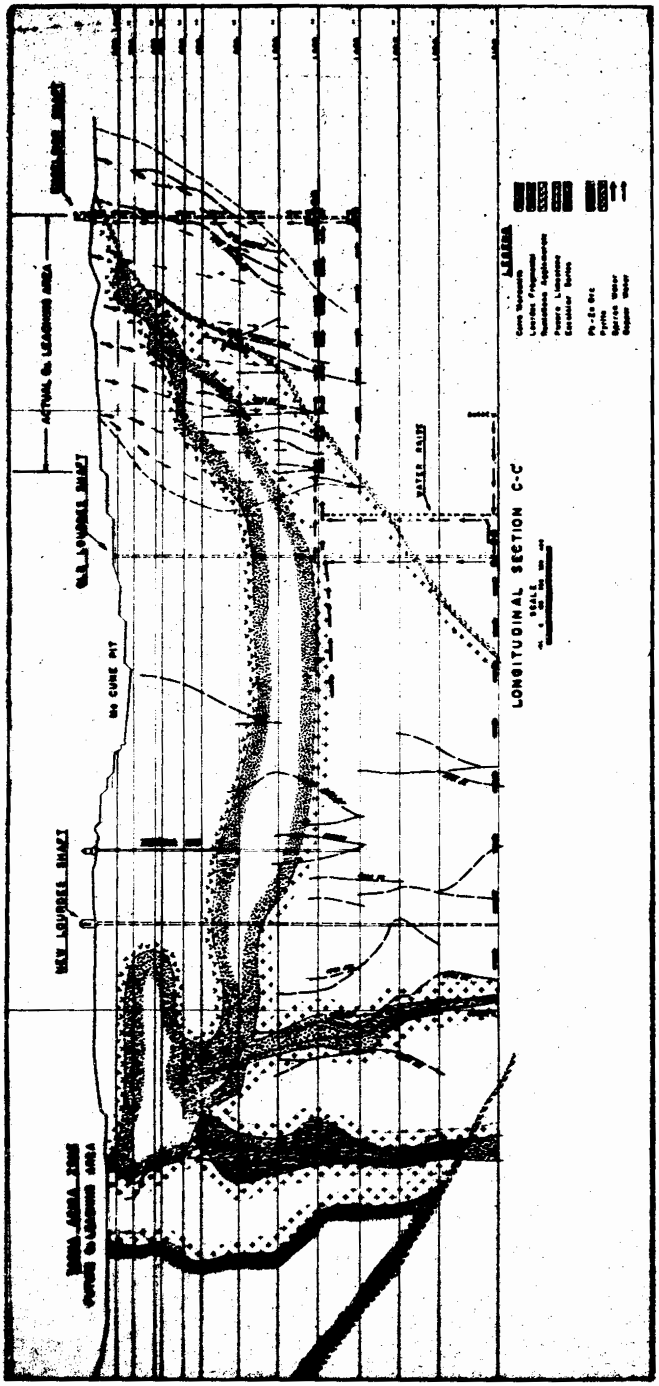
NEW LOURDES SHAFT
OLD LOURDES SHAFT
ACTUAL Cu LEACHING AREA
WATER RAISE
LEGEND
LONGITUDINAL SECTION C-C'

FIGURE 2

pyrite, bornite, luzonite, hypogene chalcocite and covellite) are found in subordinate amounts. There are solid solutions between copper minerals, as the tennantite-chalcopyrite (5:1 ratio), bornite-chalcocite, bornite-chalcopyrite, and chalcocite-chalcopyrite associations. Silver minerals are also present probably as pyrargyrites. Lead, zinc, antimony, arsenic and bismuth are also present but in minor amounts. At the northern and southern ends, the enargite changes to luzonite (it was deposited under 300°C of temperature).

HYDROGEOLOGY

The mining district of Cerro de Pasco has an average annual rainfall of 1,120 mm. (1,965-1,984), as snow, hail or sporadic rains. This mining district is a large basin of water gathering (Fig. N° 3) where works are placed in the central part of it. Westward underground infiltrations are minimal mainly because the Pampa Seca-Quiulacocha deep pass gathers the major part of infiltration waters draining them southwestward.

All water from the eastern side gathered to the large basin, fills two small basins called Patarcocha lakes and it infiltrates the saturation zone below the water table (Fig. N° 4) with an essentially westward trend. The main flow of this infiltration water is stopped and deviated northward or southward by the longitudinal thrust fault. Really it is a fault zone which has different sized limestone fragments included in a matrix which is also calcareous. Indeed, the fault is an aquifer which supplies industrial water for different uses and barren water which filters through crossing fractures and penetrates into lead-zinc mineral bodies getting contamined with the mineral powder.

In the limestone, water mainly infiltrates through fractures, karstic cavities, sandstone porosities and by gravity goes to a longitudinal fault which dips eastward. In the fault, and because of gouge, water is stopped in its westward circulation (Fig. N° 5). Only with diamond drill holes or with works which have arrived very close to the fault, we have established a communication with the fault water. In some cases, the water confinant pressure was such that it flooded the lower levels (2,300 level and below) which couldn't be recuperated up to date, even though we are using pumping systems. Logically the water flow from the fault to pumping cameras temporarilly changes the water table position, allowing the exploitation of lead-zinc mineral in fractured zones very close to the fault.

In the copper veins, mantos and bodies zone, the natural infiltration of water is minimal. This zone has been exploited by means of underground works more than 30 years ago. Now then, even though the mineralization from main veins has been extracted, there is low grade copper mineralization which was left in the walls between veins. It shows as disseminations and veinlets.

The analysis of this low grade mineralization gave the follosing results: %Cu = 0.50, %Pb = 0.79, %Zn = 0.71, and oz.Ag = 3.0. The tonnage is about 16'000,000 DST.

As it can be supposed, the existence of this mineralization and the possibility of extracting it in situ,originated the extraction by lixiviation and the concentration in the SX-EW Plant. Initial work such as tunnels was done and the studies were completed on mineralogical compositions, displacement mechanisms the recuperation percentage, and the extraction percentage for feasible in situ lixiviation to obtain copper.

The copper water flow mainly goes through fractures, and clays are not so

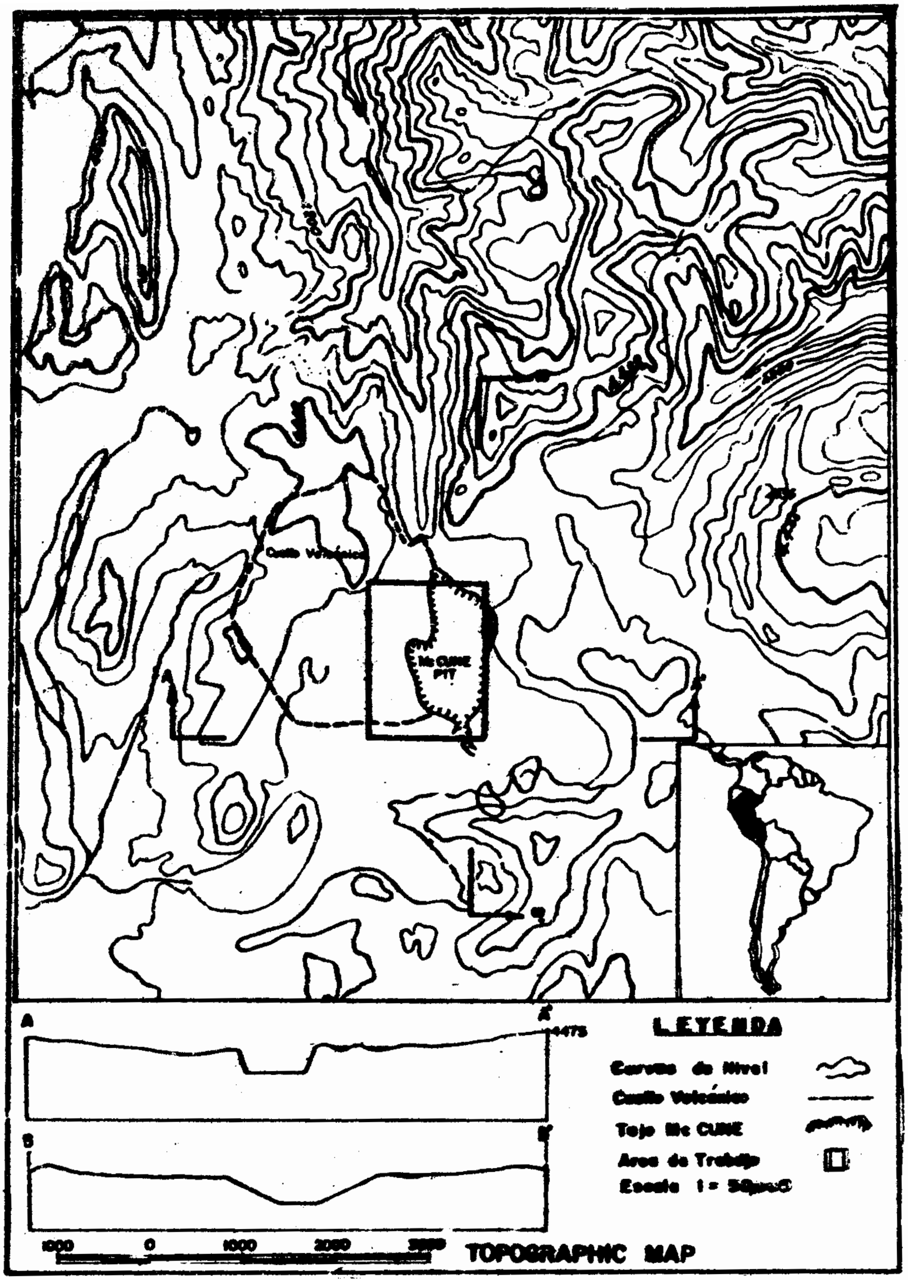

FIGURE 3

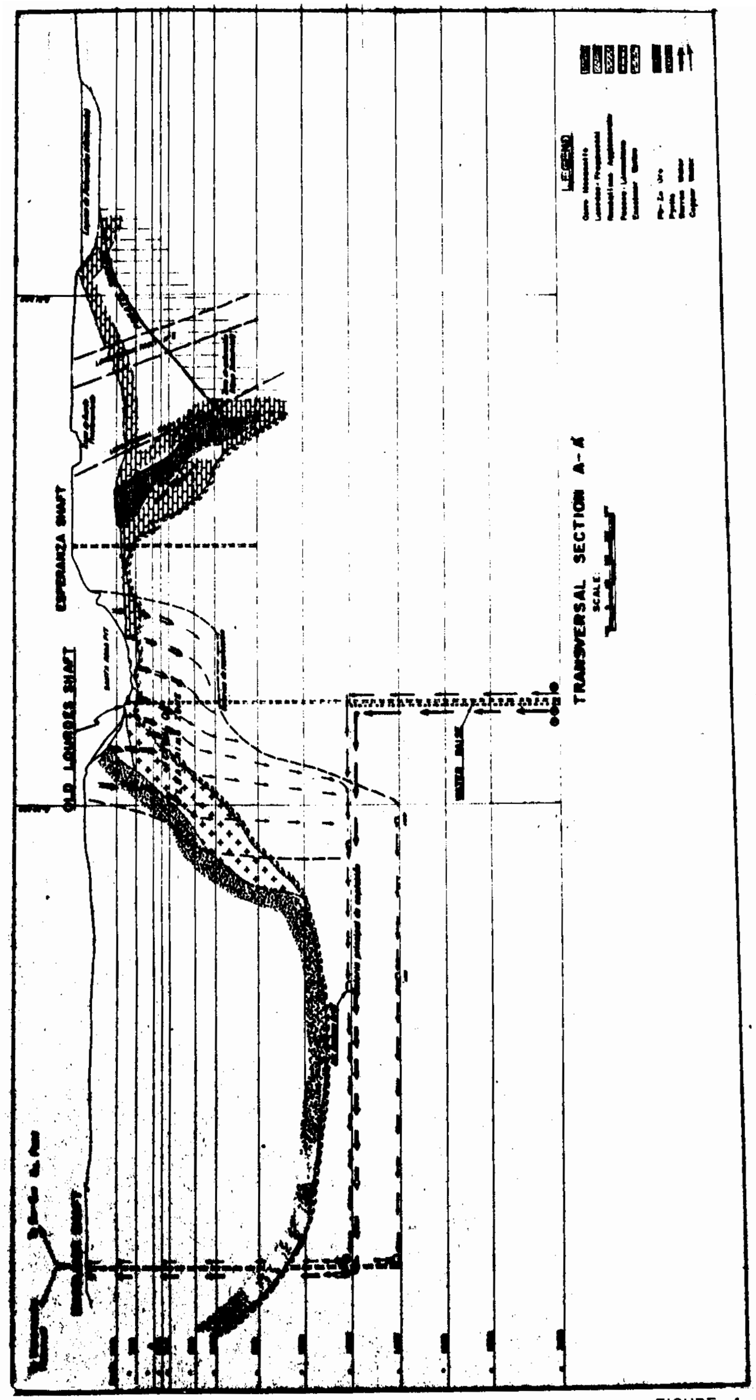
OLD LOURDES SHAFT
ESPERANZA SHAFT
TRANSVERSAL SECTION A-A'
SCALE
LEGEND

FIGURE 4

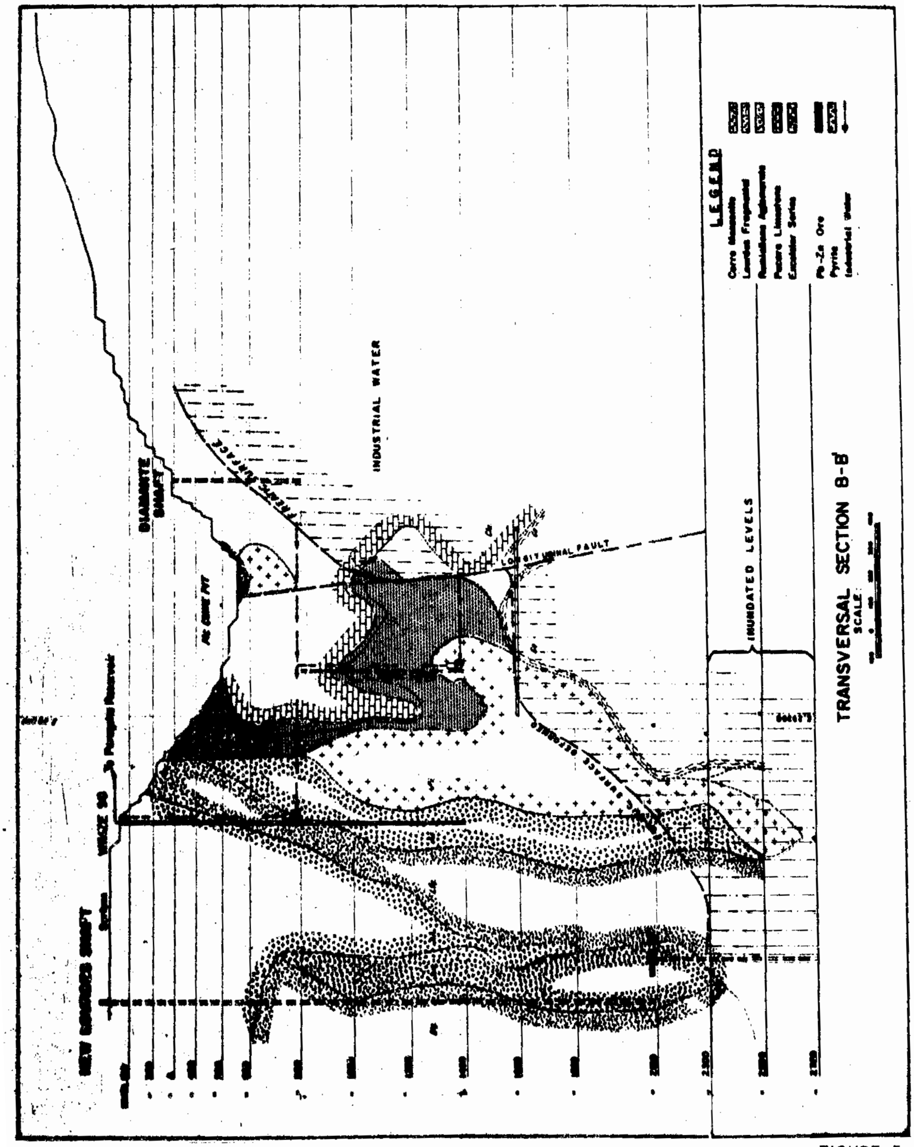
TRANSVERSAL SECTION B-B'
SCALE
INUNDATED LEVELS
INDUSTRIAL WATER
LEGEND

FIGURE 5

abundant. Anyway, we have analyzed slimes from decanting ponds and the results are: %Cu = 0.28; %Pb = 2.18; %Zn = 1.48; %Fe = 18.8; oz.Ag = 3.94. The slime is made up of clays 65%, opaque minerals 12%, plagioclases 8%, and quartz 7%. Each decanting pond is cleaned every 6 months. The barren water also has these slimes and filters them especially through vertical works toward lower levels where it is decanted before pumping at surface.

The spacement between main fractures is about 70' but affected zones by fracturing diminish this interval. As there were several stages of reactivation and formation of new fractures, veins already formed were partially crushed and opened again. This largely facilitates the lixiviation.

KINDS OF WATERS AT THE CERRO DE PASCO MINE

The Cerro de Pasco mine combines in the same area underground, open pit mining for extracting lead, zinc, silver ores and an In-Situ leaching operation for copper whose solutions are treated in a SX-EW Plant producing 5,000 ton/yr of copper cathodes. In addition, there is also a large dump leaching operation going on utilizing low grade ores extracted from the open pit mine.

One aspect that aggravates the whole operation is the presence of large flows of natural underground waters collected at different levels of the mine mainly at the lowest level 2100 feet deep.

In addition to these waters, 2,000 gpm of acid solutions are being irrigated to the mine for leaching purposes making the dewatering system formidable. Basically three kinds of waters or solutions are pumped from the mine:

a).- Alkaline waters, collected at the 800 level and pumped to the surface with a flow of 800 gpm using two 800 gpm capacity pumps. These waters are mainly used in a Concentrator Plant nearby and part is returned to the mine for refrigeration and drilling purposes.

b).- Acid Barren Solutions, which actually are the natural underground waters that became impregnated with iron and acid after percolating through the pyritic ores.
A typical analysis of these solutions, whose flow is around 3,300 gpm is (gpl): C=0.11, Fe=3.2, Zn=0.16, Pb=Tr, As=0.1, Sb=0.006, pH=2.0, H^+=2.8, Solids=2.8%. Barren solutions are collected at 2,100 and 1,200 levels (Fig. N° 6) and pumped out of the mine using two main pumping stations located at the same levels which are interconnected in such a way that the barren collected at level 2100 is first pumped to 1200 and thereafter aboveground. The pumping capacity includes 2 pumps of 2000 gpm in each level.

As these solutions naturally contain copper and sulphur-iron leaching bacteria such as thiobacillus ferrooxidans, ferrobacillus ferrooxidans and thiobacillus thiooxidans, they are mainly returned to the mine to be used as leachants in spite of their high solids content.

c).- Copper Pregnant Solutions, which results as a consequence of the in-Situ leaching operation. These solutions are mainly collected at 2100, 1400 and 1200 levels (Fig. N° 6), in separate collecting ponds and tunnels to avoid mixing with the barren solutions.

The pumping system used is similar to that employed for the barren so-

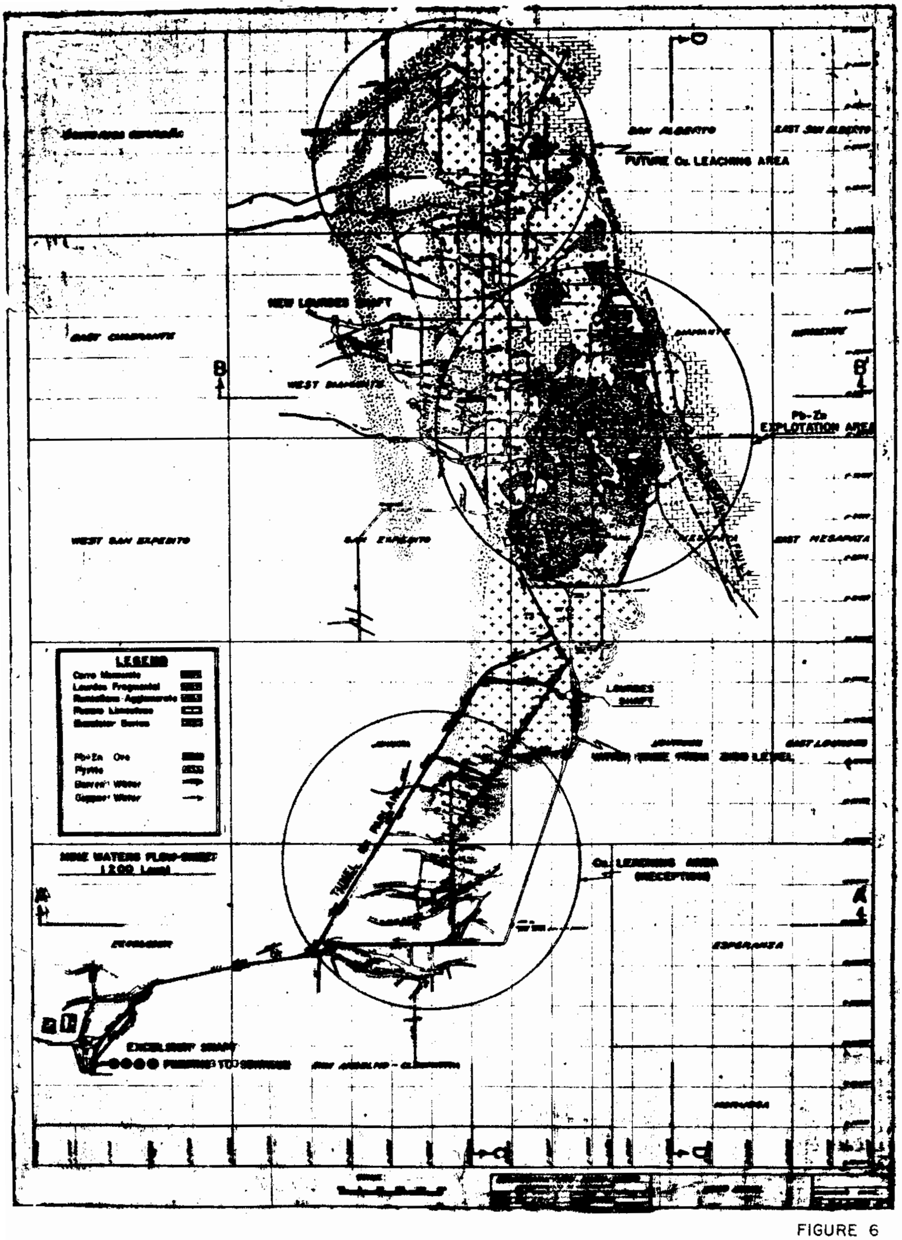
SAN ALBERTO
EAST SAN ALBERTO
FUTURE Cu LEACHING AREA
NEW LOURDES SHAFT
WEST DIAMANTE
Pb-Zn
EXPLOTATION AREA
WEST SAN EXPEDITO
SAN EXPEDITO
EAST MESAPATA
LEGEND
LOURDES
SHAFT
Cu LEACHING AREA
(RECEPTION)
MINE WATERS FLOW-SHEET
1200 Level
ESPERANZA
EXCELSIOR SHAFT
PUMPING TO SURFACE

FIGURE 6

lutions, but only one pump of 1800 gpm in each level is available, and two smaller pumps at the 1400 level, which pumps the solutions not collected at the 1200 level.

A typical analysis of these solutions is: (gpl) Cu=0.85, T/Fe=10, Zn=1.3, Pb=0.01, As=0.21, Sb=0.01, Si=0.11, Al=0.12, Solids 0.003%, ph=1.25.

Collecting and pumping the alkaline and acid barren water represents $ 0.10 per 1000 gal. While the collection, irrigation and pumping of the pregnant copper solutions is $ 0.60 per 1000 gal. In the latter case, this cost covers all expenses made for actually producing these pregnant solutions. As can be seen, these figures are still low, but they may eventually increase as the ore becomes depleted or its copper content lowers gradually as the leaching progresses, and probably the operation will be stopped when the ore contains less than 0.18% copper.

THE MAIN WATER CIRCUIT

In fig. 7 the general flow diagram of the mine water circuit is shown. From here it can be seen that the in-situ and dump leaching operations are closely interrelated and largely depend on the mine water supply, since no other kind of waters are available in such flows at Cerro de Pasco; unless all the raffinate be recycled, but this may cause some problems yet under study. In addition, an equivalent flow of acid barren solutions would have to be discharged into the Mantaro river causing unwanted pollution problems.

The total flow irrigated to both operations is around 3,800 GPM, and a good water balance has to be kept in order not to flood the mine, since the retention capacity of the reservoirs are very low not allowing more than 8 hours retention time.

The ore leached in-situ has an estimated reserve of 16 million tons of copper bearing pyrites averaging 0.5% copper, while the dumps have almost 8 million tons of ore with 0.35% copper. This ore stripped from the open pit mine is piled in dumps 10 meters high covering an area of 120,000 m^2. At the final stage, these dumps are expected to have 25 million tons covering an area of 500,000 m^2.

The in-situ leaching operation is carried out in a previously mined deposit, using caving techniques for breaking the ore and constructing tunnels directed to veins and ore bodies left by the previous mining works. As the flow pattern is downward and the general percolation profiles were already determined, the leaching solutions are distributed over the veins, bodies and backfills using 2-inch pipes. The irrigation continues until the copper concentration falls below 0.50 gpl, at which point the respective area is put in a rest period for one or two months.

The solution recovery at the mine is only 80% which means that almost 400 gpm are lost, probably by filtration and evaporation, since the average temperature at the mine is 32°C.
At the dumps this recovery increases to 88% and losses are mainly due to evaporation, which is enhanced by the aspersion type irrigation system used at a flow rate of 10 lts/m^2/Hour.

As the barren solution naturally contains sulphur-iron bacteria, leaching rates are relatively high, especially at the mine where the oxygen dissolu-

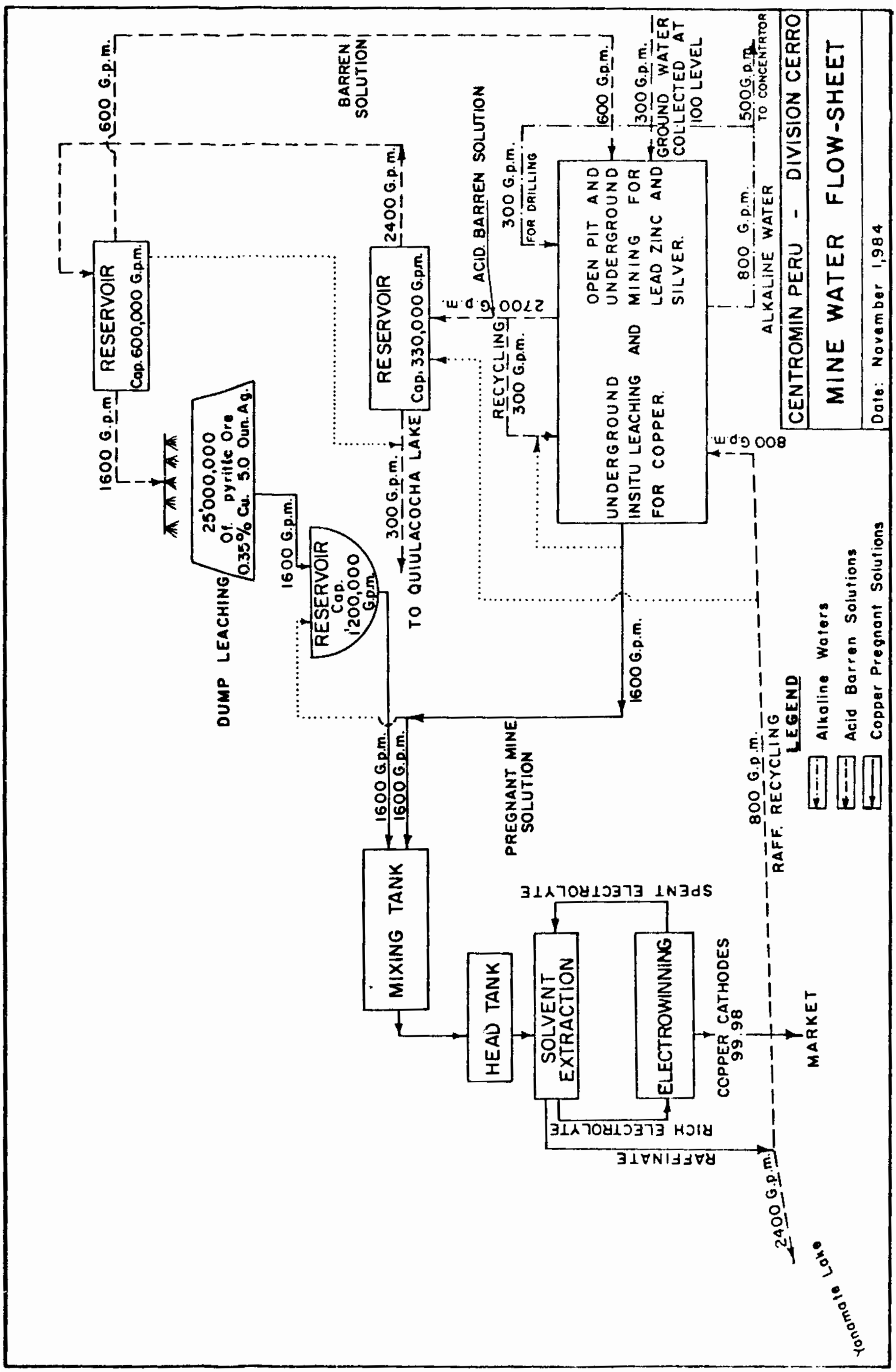
CENTROMIN PERU - DIVISION CERRO
MINE WATER FLOW-SHEET
Date: November 1,984
RESERVOIR Cap. 600,000 G.p.m.
600 G.p.m.
BARREN SOLUTION
1600 G.p.m
25'000,000 Of. pyritic Ore 0.35% Cu. 5.0 Oun. Ag.
DUMP LEACHING
1600 G.p.m.
RESERVOIR Cap. 1'200,000 G.p.m.
RESERVOIR Cap. 330,000 G.p.m.
2400 G.p.m.
300 G.p.m.
TO QUIULACOCHA LAKE
ACID BARREN SOLUTION
300 G.p.m. FOR DRILLING
2700 G.p.m.
RECYCLING 300 G.p.m.
OPEN PIT AND UNDERGROUND MINING FOR LEAD ZINC AND SILVER.
UNDERGROUND INSITU LEACHING AND FOR COPPER.
600 G.p.m.
300 G.p.m. GROUND WATER COLLECTED AT 100 LEVEL
500 G.p.m. TO CONCENTRATOR
800 G.p.m. ALKALINE WATER
800 G.p.m.
1600 G.p.m.
PREGNANT MINE SOLUTION
1600 G.p.m.
1600 G.p.m.
MIXING TANK
HEAD TANK
SOLVENT EXTRACTION
ELECTROWINNING
SPENT ELECTROLYTE
RICH ELECTROLYTE
RAFFINATE
COPPER CATHODES 99.98
MARKET
800 G.p.m. RAFF. RECYCLING
2400 G.p.m.
Yanamate Lake
LEGEND
Alkaline Waters
Acid Barren Solutions
Copper Pregnant Solutions

FIGURE 7

tion in water increases because of the high pressures caused by the water column, ensuring the supply of oxygen necessary for the oxidation reactions and for the bacteria. The leaching process can be represented by the following simplified equation:

$$MS + 2O_2 \xrightarrow{\text{Microorganisms}} M\ SO_4$$

where M is a bivalent metal, such as copper, iron, zinc, etc. Bacteria, such as the thiobacillus Ferrooxidans, catalyzes the oxidation reactions:

$$2CuFeS_2 + 8\ 1/2\ O_2 + H_2SO_4 \xrightarrow{\text{Bacteria}} 2\ CuSO_4 + Fe_2\ (SO_4)_3 + H_2O$$

The Pyrite and pyrrhotite associated with the chalcopyrite are also oxidized by the microorganisms to ferric sulphate and sulfuric acid. The ferric sulfate then contributes to the oxidation of the chalcopyrite:

$$CuFeS_2 + 2Fe_2\ (SO_4)_3 \longrightarrow CuSO_4 + 5FeSO_4 + 2S$$

This reaction has the advantage that oxygen is not necessary.
An indication at the mine that a high bacterial activity is underway, is the presence of more than 2.5 gpl of ferric ions in the solutions percolating from one level to the next, mantaining a high oxidation potential in the solutions, and ensuring good leaching rates. Unfortunately, however, iron and acid are equally leached increasing the iron and acid content of the pregnant solutions, severely afecting the selectivity and general recovery efficiencies at the SX-Plant.

Another factor that helps to maintain high reaction rates at the mine is the steady high temperature (30 to 40°C) ideally suited for maximizing the bacterial activity and enhancing the diffusion rates.

At dumps, on the other hand, the leaching rates are somewhat lower, due to the following facts:

- Compaction of the ore, especially the fine ones (17% - 10 Mesh) occluding the dumps pores, provoking heavy channeling reducing the copper recovery. Due to this, the dump surface has to be ripped open permanently in order to allow the oxygen diffusion to inner layers.

- Very cold ambient temperatures averaging 8°C through the year, and

- Very low grade ores.

These general conditions have determined that the washing periods may be as short as 3 days, requiring the use of a large labor force to keep changing frequently the irrigation piping from one dump to another.

Thus, after 20 years of continuous leaching operations, the general copper recoveries at the mine are estimated to be above 45%, while at dumps it is only 37% for the same period. Also, the cost of producing 1000 gal of pregnant solutions is lower at the mine $ 0.60 for $ 0.69 at dumps. The major items at dumps are the transportation costs of ore from the pit and the cost of using bulldozers and cats for leveling, ripping and actually constructing piles.

MINE WATER TREATMENT

The pregnant solutions obtained at the in-situ and dump leaching operations are well mixed prior to being fed to the SX-EW Plant.

This Plant has two trains, each one having 3 stages of extraction and two stages of reextraction. Each train handles 1600 gpm of a pregnant solution averaging 0.85 gpl of copper. The specific organic reagent used is Acorga P-5100 made by ICI, diluted in kerosene 4% v/v. This reagent was selected because of its high selectivity for copper in the presence of iron and high extraction rates at low pH. However, the lower than expected pH of the feed, precludes recoveries higher than 90% being at present only around 86%. The raffinate, at present, is being discharged to an old basin with little infiltration located in the area of Cerro de Pasco.
The Plant output is 5,000 Ton/year of refined copper cathodes, 1000 tons short of the estimated production, because of the low recoveries at the dumps.
The production cost at the SX-EW Plant for 1984 was \$ 0.17 per pound of copper and the overall production cost including the leaching operations was \$ 0.44 per pound.

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