Module IV

Technology and Mine Closure

MINE CLOSURE – A GEOMECHANICS VIEW

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SUMMARY

To say that the closure of a mine should be planned at the beginning of the mine planning stage may seem an overstatement. However, when the mining operation is examined under the environmental perspective, it is difficult to avoid this. The problem becomes even more complex as it is considered that the final mine configuration will depend upon the mining method selected for the operation.

It is possible, therefore, to establish the following dependency sequence: (1) the mining method depends on the grade distribution of the metal or ore mineral being mined, conditioned by the geometry of the orebody and the geomechanical characteristics of the orebody and the surrounding rocks. All these conditions have to be considered when the cost-revenue analysis of the mining operation is carried out at the feasibility stage. The parameters related to the minimization of the environmental impact of the operation are also considered at this stage.

Under this general view, this paper contains a discussion of the relevance of the determinant factors on the behavior of mine excavations. The study of this behavior may be carried out using Rock Mechanics tools, which are progressively supporting decisions on mining methods, which, at the mine closure stage, ensure the minimization of the environmental impact of a mining operation.

1. INTRODUCTION

Most mines both open pit and underground, are developed in solid rock formations. The inevitable implication is that all determining factors of the final outcome of a mining operation are associated with the structural characteristics that delineate the mechanical behavior of the rock formation.

In a more direct approach, a mine will be the more economically feasible the simpler the solutions for the extraction of the waste associated to the orebody. And the amount of waste to be removed is directly related to the mining method selected. Therefore, in an open pit mine, the relation between the volume of waste to be removed and the volume of ore obtained will be the smaller the better the mechanical strength quality of the orebody; the steeper the slope angles, the smaller the blasting costs, the smaller the transport costs and the waste dumps.

Because of the relationship between the geomechanical quality of the rock formation and the volumes to be removed, it is certain that the environmental impact related to vibrations from blasting operations and transport will be smaller. The amount of investment for mine reclamation will also be smaller.

In underground mines, there will also be a similar relationship between the geomechanical quality of the rock formation and the mining costs, reclamation costs and the eventual re-use of mine openings.

2.MINE PLANNING

Planning means knowing the problem. All planning efforts will be the better the deeper the knowledge and information about the parameters relevant to the problem. However, knowledge means investigation and investigation demands costs which are proportional to the complexity of the object of the study. On the other hand, we know that financial risk control requires that costs be incurred as long as there is a safe and progressive expectation for their return. Therefore, planning of economical activities is usually established with increasing levels of certainty, as long term, medium term and short term planning.

This occurs also in mining. However, the parameters that are taken into account in mine planning are those whose importance is clearer. This will mainly be those where measurement and control techniques in the mine are known.

Even if currently well known, geomechanical parameters, mainly those strictly related to Rock Mechanics, are usually considered expensive in their evaluation and measurement methods. The degree of control that can be applied to these parameters is somehow limited dispersing with the current level of technical knowledge.

3.THE GEOMECHANICAL PARAMETERS

The geomechanical parameters mentioned above are those used for quantifying or assigning some measure to the specific properties of rock formations. These are listed below to ensure that the ideas transmitted here are conceptually supported:

Properties related to the physical nature of rocks:

Rock density.

Rock porosity.

Rock hardness

Rock texture.

Properties related to the mechanical strength of rocks and rock masses:

Compressive strength.

Shear strength

Poisson ratio

Modulus of deformation.

Cohesion.

Angle of internal friction.

Shear resistance of the rock joints

Parameters related to geology:

Stress state in the rock mass.

Lithological features of the rock mass

Particular Parameters associated with the structure of the rock formations:

There are ten parameters associated with the discontinuities as illustrated by the figure below, (after J. Hudson)

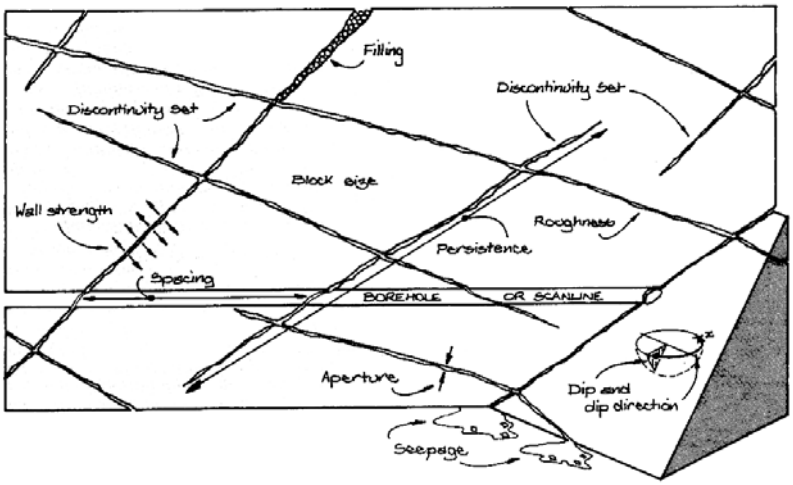

Figure 1. Illustrative diagram of rock mass descontinuity properties and water seepage (After John Hudson, 1989)

If on the one hand many mining operations do not consider and investigate geomechanical factors in an appropriate manner, on the other hand, modern companies, more technologically advanced, clearly recognize their importance. The main reason for this is related to the potential problems in the mining operations if geomechanical factors are not properly considered; when these are not considered, not only potential problems during mining may occur, but also during the closure of the mine.

3.1.The investigation

Whenever possible, the progressive planning of expenditures in a mining operation is a desirable alternative. Once the financial feasibility of a mining enterprise is confirmed, the most appropriate practice to avoid problems is the investigation of geomechanical factors in the orebody, during the pre-mining phase of the operation.

The author of this paper has been focusing, mainly in his recent research, in the economic, safe and low-risk benefits of activities such as exploratory drillholes, instrumented stopes, and stability systems testing. These activities may be carried out at the same time as the grade sampling and investigations for reserve estimation during the exploration phase before mining. The simultaneous execution of these investigations would certainly be cost efficient: if investigations for grade and reserve estimation are routinely carried out at this phase, geomechanical investigations have an equal degree of importance in the determination of the mining method and in the structural planning of the underground openings required in the mine.

However, in most cases, geomechanical investigations are completely ignored or relegated to future phases of the operation; in such cases, they are only taken into account with the occurrence of structural stability problems, with the false idea that they would be implicit in a mining operation.

A number of research groups, in various parts of the world, have been concentrating on the development of new techniques to determine better definition of underground structures by using 2D, 3D and 4D seismic. Among them are the DELPHI

project at Delft University and the Geological Research Center of Edinburgh University, in Scotland, the latter with long experience from reservoir projects in the North Sea.

Figure 2 below shows sub- surface rock quality variations obtained by the Norwegian Geothechnical Institute (Barton, 1996).

The " cross-hole velocity tomography " technique was used in the investigations associated with construction of the 62m span GjØvic cavern for winter Olympic sports held in Norway in 1994. A strong link between seismic velocity, rock quality and rock support needs was established.

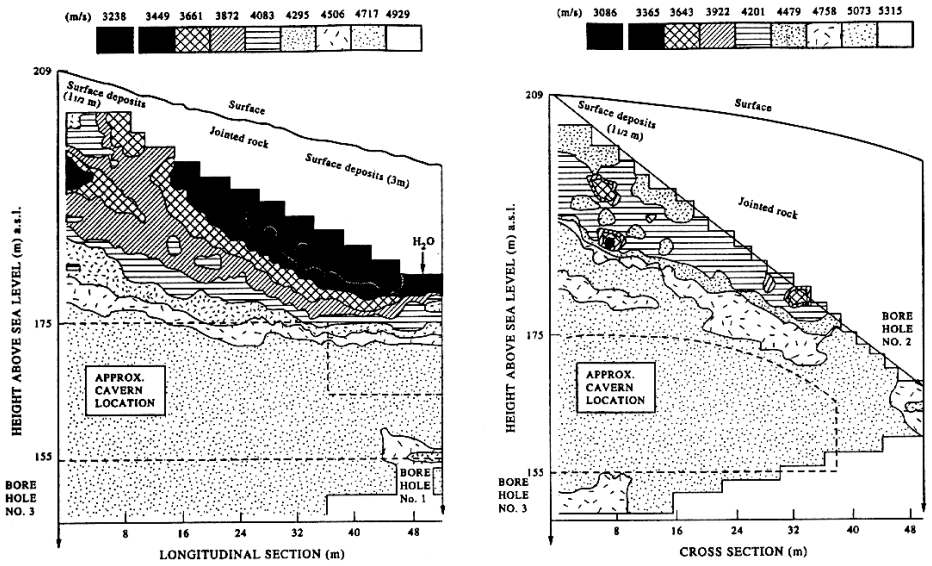

Figura 2. Seismic tomography (" cross - hole "), in the location of the olympic cavern at GjØvic (after Barton, 1996).

3.2. The economic implications

It is interesting to observe that the argument on the necessity of geotechnical and structural implications during mine closure brings up the fact that we are still discussing the need to start up the investigations during the mining operation itself. This may be justified by the fact that only recently Rock Mechanics has developed sufficiently to give the technical-economical decision-makers a clear vision of the technical advantages and the cost and risk reductions related to using the specific tools of this area.

For example:

- In an orebody where it is known:
- the grade distribution of mineable reserves,
- the volume to be produced in a particular time horizon,
- the strength and stress status in the rock formation, with the magnitude and direction of their components,
- the structural mechanical characteristics of the formation (presence and characterization of discontinuities, folds, fractures and their spatial position),

- the mechanical strength characteristics of the rock formation (orebody and surroundings);
- it will be possible to establish a geomechanical model that will allow the better definition of the directions of underground drives and stopes with improved stability. This will mean lower costs with roof support systems and will avoid costs with recovery of damages that could eventually occur with unpredictable risks.

The construction of a geomechanical model will also allow the selection of a mining method with lower operating costs and may avoid mining methods that would become impractical for those particular conditions.

This approach has been followed in a few technically equipped and well capitalized mines, where the mechanical behavior of the mining excavations have been well monitored and predicted. This has allowed the prevention of problems in the mine operation, using global solutions such as mining methods compatible with the mechanical nature of the orebody, with forecasts of structural difficulties at the end of the mine life.

4. THE MINE CLOSURE

As discussed above, it is clear how geomechanical models can contribute in the mine closure analysis.

In open pit mines, it is easy to realize that the mining method and the slope angles will not only depend on the orebody grade distribution and geoestatistical configuration, but also on the structural characteristics and mechanical behavior of the rock formation (orebody and surroundings). This will provide the total volume of the excavation and its spatial distribution. Further studies will allow the decision on the need for waste dumps, their configuration and procedures for slope stability perhaps through re-vegetation of the waste dump slopes? This phase of the study will certainly be associated with future land uses: recreation areas, perhaps with lakes and the setting up residential areas with progressive landscaping of slopes and waste dumps; land reclamation and re-vegetation.

Here we are not addressing the issue of water contamination, which is discussed later.

4.1.Underground mines

The appropriate use of Rock Mechanics allow the construction of analytical, physical and numerical models that are then used in decisions of the correct mining method in technical and economical terms. During mine closure, the same approach will allow the verification of the mining method chosen and the stability of resulting excavations. Each particular method considered here may be applied to the mine overall or individually by region, because the same orebody may have different regions exploited with different mining methods. In the present analysis it is considered that each example is associated with a specific mining method. Even the selection of a mining method requires methodologies and care related to its technical definition under given geomechanical aspects. What is being proposed is that such solutions are extended to the final phase of mine closure, with a verification of the actual compatibility of the selected mining method with an acceptable level of disturbance to the environment.

If eventual damages from the selection of a particular mining method cannot be minimized to an acceptable level, it will be necessary to investigate the adoption of an alternative method, where the resulting environmental impact is the lowest possible. A curious fact is that the final solution, with the lowest environmental impact, will certainly be

the one with the lowest global cost, which includes all required reclamation costs. Recently, this has become compulsory in all activities dealing with nature, by law.

a. Analysis of a case study

A mining company started a mining operation in the thickest layer of a particular manganese deposit, where the orebody is divided into 3 layers outcropping in the side of a hill, with average thickness of 4m, 1m and 0.4m. The overburden was 150m at the highest point. Mining started in the 1970s. The mining method selected, based on previous experience from the 1920s, was room and pillar.

The average cross-section of the pillars was 4m by 3m, with span of approximately 4m in the room. Mined ore came from the thickest layer, with ore left in the pillars, which were not mined. The method was properly developed and supervised at that time, with the classical approach of leaving flag-pillars to indicate isolated areas. Mining continued for several years without problems and with a low waste extraction rate, because all the ore being mined was processed in the plant to produce alloys.

The main environmental impact came from the steel plant, through the emission of particulate material and ashes. This was reduced to trace levels after the introduction of appropriate filters.

At a certain stage during the 1980s, with the objective of obtaining a higher recovery, but without using Rock Mechanics information already available, the technical staff responsible for the mining operation decided to change the mining method. They started to reduce the cross-section of the pillars, and to transform flag-pillars into regular pillars, even though they still had a considerable ore reserve available. The objective was to maximize the profit of the operation with the decrease in mine development costs.

With the increase in the span, the result was the development of higher tension and shear forces in the roof with the progressive damage to the pillars – from the borders to the inside of the mine – which has caused the rotation of a large area in the slope. The resulting strain rupture patterns, later visible at the surface topography of the hill, were allowing the penetration of rain water, which made them wider. The pillars were then shortened, with a gradient increasing from the inside to the outside, and the overburden area of a larger portion of the mined out region has rotated as a large single block, thereby closing down the mine entry. The progressive crushing of the pillars, with the compressive strain leaning in its axis, has resulted in a large slide of the slope.

The reclamation costs are being considered impractical. Currently, the mine is under water and closed down. Later studies have allowed a better understanding of the process. If these studies were carried out at earlier stages, they could have prevented the problems and could have oriented a better refinement of the mining method. A brief explanation is presented below:

- Simple compression tests over the manganese ore have shown that the compressive strength of the orebody, considering a scale factor, is approximately 51 MPa.
- In the most critical region, the average strength on the pillars was approximately 4 MPa.
- 4m x 3m pillars with 4m gaps, according the tributary area theory, are submitted to a compressive charge of 23.130 tnf. The pillars could resist to a nominal charge of 61.918 tnf. This relates to a Safety Factor of 2.68, which is appropriate for this rock type, considering the scale factor for the compressive strength. With the increase in the spans (which means to decrease the cross-section of the pillars by 1m), the Safety Factor comes down dangerously to 1.7.

-The orebody layer has discontinuities forming 3 different families, in addition to random planes, with the most critical ones being close to 45º in dip.

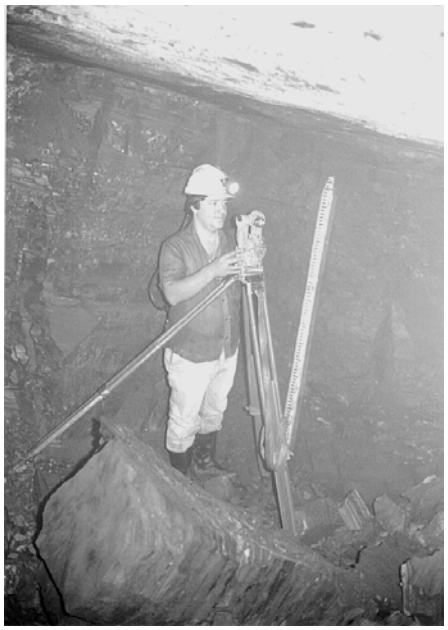

Figura 3 - Illustrative picture of the sampling of blocks to determine the rock mass strength parameters (surveyor gives scale) (after Ayres da Silva,1992)

- The surrounding rock formation is an arcose (roof and floor), with an average thickness of 20 to 40 cm, significantly altered, over which there is a jaspelite with families of discontinuities with horizontal, sub-vertical and inclined planes, spaced by approximately 40 to 50 cm.

The increase of the spans has induced the increase in strain ruptures in the roof. These events were followed by a differential damage to the pillars, described in more detail by Ayres da Silva, et al. 1995.

The description above were extracted from the conclusions of research work carried out by the author with the use of experimental and lab-based tools, including the software UDEC **(Universal Distinct Elements Code)** for the numerical modeling of the rock structures.

5. CONCLUDING REMARKS

The ideas presented here hopefully support the principle that mine planning should provide the selection of a mining method that allows the economical extraction of the ore and requires a minimum volume of resources to mitigate eventual environmental impact, with an increasing degree of precision in the horizons where it is applied.

This will be possible if the company carries out the appropriate effort to investigate the relevant geomechanical parameters, in order to build a geomechanical model of the orebody.

It is also important to note that some of the alternatives being considered in this discussion, including methods that provide the refill of open stopes, or further utilization of mining openings for other uses, are being compiled by the author into a classification system to support the decision on which method should be applied.

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DECREASE OF POLLUTION BY MERCURY IN GOLD MINING IN LATINAMERICA

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ABSTRACT

It is known that mercury has a high pollution level and it is used widely in small gold mining in Latinamerica. Mercury has been used many times without needed precautions causing a big contaminant effect both in water, land and in workers than manage mercury.

On the other hand, this practice is the only possible to benefit those minerals since it requires less technology and investment, which means it could continue in use during a lot of time. Although some handicraft devices that decrease contamination, such as distillation retorts for amalgam, in the amalgamation process, keep still producing huge mercury losses.

It has been proved how it is possible to decrease mercury losses, washing mineral with detergent or alkaline agents, and using electrolytically activated mercury. This was compared with another usual methods and at the same time, it was proved that it is possible to get an increase in recovering gold that will be the main purpose of miners to use this technique.

In addition, it has been proved that it is precise to determine the proportion of mercury/mineral to use in an optimal amalgamation time to get less contamination as possible, which can be done with simple calculations.

Mercury losses (if retorts are used in distillation of amalgam) in amalgamation process are concentrated mainly in solid residues since in water used for the process contains normally from a hundredth to a thousandth or less part of what is found in solid residues. That is why solid residues are the main source of contamination above all looking to the future. Therefore it is offered as a palliative way of this problem the possible previous gravimetric concentration and the later amalgamation of concentrates, decreasing the volume of residues and making easy its safe removal or is treatment.

All these actions require neither expensive equipment nor a lot of knowledge and they improve gold recovery; therefore, they can greatly accepted by miners and they can be really effective in decreasing pollution caused by these activities.

Key words: Gold, mercury, amalgamation, pollution, preconcentration.

INTRODUCTION

The amalgamation technique is still widely used to extract gold by small miners, mainly in the tropical zones developing countries of the world. This technique is used because of it is very simple and it is efficacious, and above all, because it requires a small investment of money. We are referring in this article to this small art of mining since the big mining normally takes the need cautions and it controls its processes.

In the amalgamation process, gold is trapped by mercury in a watery pulp hole to form a highly viscous substance bright white colour, named amalgam. The final recovery of

the precious metal is made through a strong heating of the alloy (mercury evaporation) or using nitric acid (mercury dissolution).

To get that gold is amalgamated it has to be in touch with mercury. Therefore gold included in another substances (for example sulphurs or quartz), cannot be extracted until getting a milling in such a way that all metallic particles are liberated or gold can have contact with mercury. Gold is amalgamated the same that some minerals of itself that are alloys of gold with another metals like electrum, propecite (gold and palladium), gold amalgam, (Au and Hg in natural occurrence), but another minerals of gold are not amalgamated, mainly in composed of tellurium like sylvanite and calaverite.

The inadequate use of mercury in these explorations lead to high loses, both in form of elemental mercury during the mineral benefit and in form of vapour and inorganic composed during the work of separation gold–mercury. Another important part which is common for all small mining is the low level of recovery of the precious metal caused by the defective application of amalgam.

Risks about health and environment are not taken into account by miners. They ignore the damages that a bad handling of mercury. The exposure to this substance not only is limited to workers but also it is extended to their relatives, since miners and traders, in many cases, distil amalgam in their kitchens or in the backyard of their houses (1) (2).

Mercury once it is absorbed by man, goes to the sanguine torrent, easily cross over the cellular membranes and it is accumulated in the liver, the bowels, kidneys, nervous tissue, etc (3). Chronic exposure to mercury caused the famous professional illness known as “mercurialism” or “hidrargirism”.

In the environment mercury is accumulated mainly in form of metallic mercury (Hg^o) and composed of Hg^{++} and Hg^{+} like it happens with nitrate of mercury produced in the chemical separation of amalgam, in sediments of rivers and soils, where through bacterial action and under some conditions it can become organic mercury, especially metilmercury (4). This form of mercury which is highly toxic for human beings can be accumulated in water organisms and pass to man, for instance, by eating polluted fish.

However, the most urgent worry is related with health of miners and their families, because they are exposed permanently to mercury. In this sense, the following are the situations of high danger that have been recorded in all exploitations of the zone, and in which mercury can easily penetrate in people:

Exposure to mercury vapours during amalgam processing to open fire (“burn of amalgam”) in order to separate mercury of gold.

Handling of metallic mercury without any protection during the different stages of the process.

The following are some data that reflect the problem in Latinoamerica:

- In mining of south of Colombia are emitted from 3 kg to 10 kg of mercury per 1 kg of produced gold. As a middle value it can be taken 5 kg of Hg per 1 kg of produced Au (5).
- The primary mines in Brazil and Bolivia that use mercury directly in mills to achieve the simultaneous amalgamation lose from 5 kg to 10 kg of mercury (in extreme cases until 25 kg) to recover just 1 kg of gold (2).
- In alluvial mining, the loses are very similar to the above ones, when mercury is added directly to the auriferous gravel in situ, or in a mixer bowl placed before the small channel

or directly in the channel. Some of the countries that use this method are Venezuela, Colombia and Brazil (2).

- The average loses of mercury in informal miners of Brazil ("garimpeiros") has been estimated in 2 kg/kg of produced gold (6).
- The emitted mercury in the Amazonian complex are calculated in 300 t per year and until the present the accumulated quantities are from 1000 t to 2000 t in this important ecosystem (7) (8).

The annual quantity of lost mercury per about 100.000 miners in Equator is estimated in 50t.

In spite of the above data, amalgamation in a near future will carry on being the preferred method and will be still applied to small gold mining. Therefore it is important to improve technique conditions of the process through using simple technologies and easy handling equipment, lower costs of local manufacture. At the same time, it is necessary to consider the increase of recovery of gold and the lost of mercury, because its decreasing shouldn't produce the lower production of gold and this fact is very significative in order to miners participate in a project which will help to decrease the lost of mercury taking into account that if they find this project as a way to diminish their entrances they will not participate in it (they think that pollution effect are not important because theses effects are not immediate).

Technologies and equipment that have begun to be accepted are amalgamation in "closed circuit" in barrel of concentrates, distillation of amalgam in retort which make possible the recovery of mercury from amalgam and avoid its emission to the atmosphere, and activation of mercury through electrolysis. All of these require to be integrated to a mine–metallurgic coherent process. A description of a type of these retorts can be found in (10).

EXPERIMENTAL SECTION

In order to do the experimental study about recovery of gold and reduction of lost of mercury samples of mineral have been used which come from "La Bruja" and "La Gruesa" veins from the gold mine "Nueva Esparta" in the South West of Colombia, which is a bed of mineral of the lodge kind.

In table 1 the main characteristics of both samples are shown, being the sample from "La Bruja" a good example of mineral of high riches, while the sample from "La Gruesa" can be an example of mineral much more abundant in South America than in another places of the world.

Table 1. Samples Characteristics

CHARACTERISTIC	ORE	
	"La Bruja"	"La Gruesa"
Au (g/t)	317,40	44,40
Ag (g/t)	180,10	62,20
SiO_2 (%)	83,35	88,35
TiO_2 (%)	0,23	0,18
$Al_2 O_3$ (%)	3,79	2,57
$Fe_2 O_3$ (%)	3,30	2,31
MnO (%)	0,03	0,03
CaO (%)	2,11	1,56
MgO (%)	1,34	0,89
K_2 O (%)	0,88	0,59
Na_2 0 (%)	-	-
$P_2 O_5$	0,02	0,01
S (%)	1,35	1
Pb (%)	0,19	0,13
Zn	0,17	0,13
Loss on ignition (%)	4,64	3,50

All the analysis of gold of solid samples (ores, tailings, concentrates) have been done through fire assay and cupellation, which determines the content of gold in the precious metal button, by attack with nitric acid (after inquartation if it's necessary) or by microanalysis in electronic microprobe.

It is important to stand out that native gold which the samples content has silver in a proportion that could make the mineral to show "electrum" (natural alloy with approximately 20 % silver) and not gold as such element. These analysis of gold and silver content in gold that samples have and made through electronic microprobe are shown in Table 2 as a measure of the got results in several grain of both kind of mineral.

Table 2. Mean Analysis Of Several Grains Of Native Gold

ELEMENT (g/t)	ORE	
	"La Bruja"	"La Gruesa"
Au	75,70	80,40
Ag	24,30	19,60

It is also important the presence of sulphurs such as pyrite, arsenopyrite, galena, etc.

Amalgamations have been done on natural minerals, after an adequate milling in less than 2 mm, and also on concentrates of the same minerals got by gravimetric concentration (Wilfley shaking table) or by froth flotation, with the purpose of studying the influence of these processes.

All devices, products and equipment to treat the mineral until to get gold have been chosen taking into account that they are easy manufacturer of lower costs and good use by small miners in order to get results comparable to real mining.

Amalgamation has been done through barrel amalgamation in which mercury and mineral are content into a closed rotator recipient without leaks of pulp and without direct intervention of operator. The main variable operations that have been taking into account are: amalgamation time, quantity of mercury, quality of mercury (normal or activated through electrolysis) and after the mineral have been washed.

One of the measures that must be taken in order to control production of mercury "flour" (very small droplets of mercury that non coalesce) that give rise to important lost of mercury through dragging with tailings or water is not to do milling and amalgamation simultaneously in the barrel (10). The samples were milled separately in less than 2 mm.

Rests of amalgam and mercury are picked up through decanting and dragging of sterile with water. Amalgam is separated through pressure hand filtered with a weaving (a piece of weaving where the mix mercury–amalgam must be twisted) using latex gloves and finally separation of gold from mercury made by distillation in a small manufactured "retort", screw and nut closed, which are being introduced to miners because they allow to recover mercury from amalgam and help to avoid distillation in opened recipients.

For the essays with activated mercury, the mercury that comes from recovery is submitted to electrolyses in a small manufactured cell, as those ones that miners are beginning to know, which are made from a small plastic recipient that in the bottom has a graphite electrode (cathode) which is connected to the negative pole of a battery of 9 or 12 volts (car battery). Upon this electrode a layer of mercury is put and upon it a solution to 10 % of NaCl is poured (kitchen salt) and into this solution another graphite electrode is put (anode) connected to the positive pole of the battery and the electricity has to pass for about 5 minutes. In this way, something of amalgam of sodium is produced in the mercury which also reacts with water to produce hydroxide of sodium and in conjunct they clean the mercury mainly from oxides that it has in its surface. The active mercury has a strong metallic bright and tend to form almost perfect spheres when it is divided in drops that coalesce quickly among them.

For the trials with washed mineral, the mineral is submitted to the action of a lot of water in a rotary drum with lime or soda and/or detergent, decanting the water from the washing before passing to the amalgamation. This process cleans and eliminated certain covers from the grains, and it makes possible to work with alkaline pH which decrease formation of mercury flour, since it is favoured (11) by the presence of sulphurs that reach with the small drops of mercury produced by mechanic action, covering them of a layer of HgS that makes that the electrostatic repulsion of the sulphide surface layers means that the droplets repel each other and cannot become reunited. In the alkaline medium (12) the complex HgS^{2-} is formed and it avoids the covering and repulsion of the small drops.

For the essays with previous concentration of mineral a Wilfley shaking table has been used. This is a device known by miners and in many cases allow to have manufactured constructions that are cheap. Its handle is very simple, although it can require of a motor that can be electric or by explosion to be used in remote places, or even it can be moved with a manufactured wheel for drawing water.

For the essays of flotation a cell Denver Sub A has been used. This is scale model of a very big equipment adequate more for median mining than for small mining because it requires much more knowledge and reactive.

RESULTS AND DISCUSSION

Through the research it has been shown that the best results are got using activated mercury and making a previous washed of mineral with alkalis or detergents which eliminate clays and very small particles, cleans the surface of small grains and remove grease as well as decrease the influence of minerals benumbed of amalgamation as the sulphurs are. In these optimal conditions and for the mineral from “La Bruja”, the Figure 1 show the influence of the quantity of mercury used, expressed in kg of mercury per ton of mineral, with relation to the recovery of gold expressed in % also related to the total lost of mercury (the sum of the lost in decanting water and washed of the amalgamation process and lost of solid rests) expressed as grams of mercury per 100 g of produced or recovered gold.

It looks clearly the influence of mercury quantity both in the recovery of gold as in the lost of mercury mainly. The optimum quantity is 3 kg of mercury per ton of mineral, which gives a recovery of 94,.20 % of gold and a lost of 2,4 g of mercury per 100 g of recovery gold. With less quantity of mercury the quantity of gold is less by the time of given treatment and at the same time the amalgam is too consistent and coalesce badly making easy the lost in small drops that furthermore drag the gold.

When quantity of mercury is higher a similar effect is also produced due to the amalgam turn more liquid and there are more chances of lost of small drops. It has been deduced that in each mine is necessary a study in order to determine the optimum quantity of mercury to be used since this not just decrease the pollution diminishing lost of mercury to a minimum, but also it produces an increase in recovery of gold which is translated into a greater economical benefit for the miner.Another important aspect is the relation between lost of mercury in the water of the process and in the solid rests of amalgamation. In Table 3 these data are shown for the samples of the Figure 1.

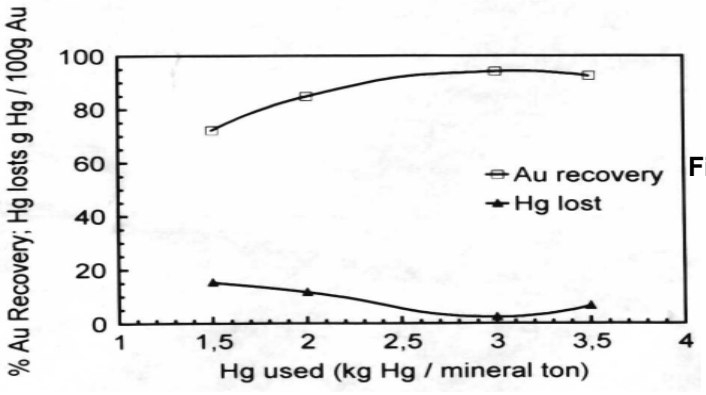

Figure 1

From Table 3 and another data from another essays, that coincide with theses, it is deducted that lost of water are from 100 to 1000 times minor that in solid, (and sometimes even minor); therefore the storage or deposition of these solid is very important as a mean to control pollution and there is where preconcentration techniques fall into because decreasing the quantity of mineral to amalgamate also the quantity of polluted solid rests to be deposited or treated decrease.

Table 3. "La Bruja": Mercury Losses In Almalgamation Of Previously Washed Mineral With Activated Mercury During 2 H.

MERCURY USED (Kg Hg/t)	MERCURY LOST (g Hg/100 g Au PRODUCED)	
	IN WATER	IN SOLIDS
3,5	0,06	6,50
3,0	0,008	2,40
2,0	0,0005	11,60
1,5	0,16	15,30

Operator conditions, mainly in what concern to the previous washed of mineral and the use or not use of mercury previously activated, have a decisive importance in reference to pollution caused by mercury and also in the recovery of gold. In Figure 2 results of using 3 kg of mercury per ton of mineral are shown. 3 kg is the optimum proportion according to Figure 1 with an amalgamation time of 2 hours and in the operator conditions above mentioned.

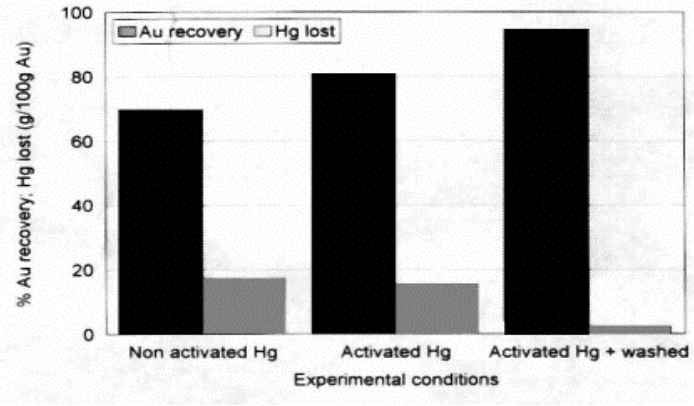

Figure 2

It is possible to observe how the recovery of gold growth significantly by using activated mercury and then by using this mercury upon previously washed mineral, but above all, all what decrease is the contaminant effect which is reduced to a eight part compared with using non activated mercury.

This beneficial effect of the activated mercury and of the previous wash is kept even if the optimum time or the quantities of mercury are not taken into account. It could be said that its effect is even higher in these cases. Thus in Figure 3 the results for a quantity of 3,5 kg of mercury per ton of mineral are shown. The excessive time of 4 hours makes easy lost due to the shred of mercury and amalgam (formation of mercury flour).

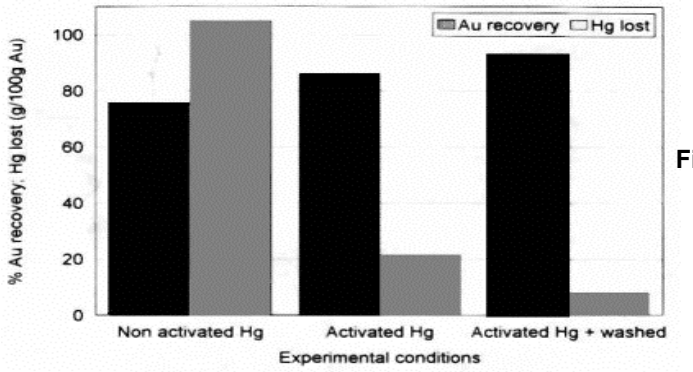

Figure 3

In this case there is an improvement in the recovery of gold, but the lost of mercury are reduced to the thirteenth part. In any case lost are higher that in the case of Figure 2 (2 hours and 3 kg of mercury per ton) and recovery of gold is lower, which show the importance of time of treatment, especially in formation of mercury flour.

Results of essays with activated mercury, at the same level than another conditions, have given better results always, referring to relative lost of mercury that in normal assays with normal non activated mercury. The microscopic exam of the sterile samples of the treatment with activated mercury, previous to a strong shaking to concentrate heavy minerals, showed less fine grains of lost gold than when the assays are done with non activated mercury. Spheres of activated mercury and gold amalgam are joined quicker and efficiently than in the case of non activated mercury, avoiding lost of gold and it requires less mercury for its collection. The amalgam filters better and its appearance is more solid, brighter and united in a mass than later will make it easy the formation of a sponge of gold more compact and easy of extract during distillation in the retort.

The most important aspect of this study is to have determine the function that the previous wash has. In this sense, the assays done during equal time and with the same quantity of mercury, activated or non activated, produced much better recovery of gold and relatively less lost of mercury when the mineral was submitted to a previous stage of washing. This simple operation eliminates grease substances from the pulp, removes the cover or patina that gold grains could have and minimises the action of another "amalgamation benumbed substances" (arsenic sulphurs, antimony, bismuth, lead, iron, copper, etc.) that contaminate mercury and appear in almost all beds of primary minerals of gold lodge type, as in the case of the mineral of the veins "La Bruja" and "La Gruesa".

Another conclusion from the experiments done with previous washing is that it is possible to decrease dosification of reactive and time of treatment to get the same recovery of gold, which implies less costs of production and higher entrances of resources represented by recovery gold and mercury, and at the same time less pollution is produced. Recovery of silver is always minor than those for gold, and the content of silver of the recovery gold is always just something higher than the content of silver of the native alloy gold–silver, which show that silver alloyed with gold is only amalgamated and almost nothing of this metal content in sulphurs.

The mineral from "La Bruja" is too rich in gold to be taken as a general case, although it is very illustrative of the efficacy of different used amalgamation processes. The mineral from "La Gruesa" represents in a better way most of minerals of lodge type from South America.With it, it is possible to see the same tendency, but because it has less

content in gold, recovery are lower and lost of mercury per kg of recovery gold are higher. But working in the optimum conditions (using 3 kg of gold per ton of mineral, activated mercury and previous washing of mineral in 2 hours time of amalgamation) it is possible to get recovery of 92 % in gold and lost of mercury of about 8,6 % per each 100 g of produced gold. These are from 20 to 100 times less than common lost dated in done studies about this topic.

To see the influence of the used technique the Figure 4 shows the case of using optimum conditions referring to mercury quantity and amalgamation time (3 kg/t, 2h). It is possible to see how recovery increases until 92 % and it remains to 2 points under of "La Bruja" case, and also how the lost of mercury are decreased as well, although they are higher, mainly with non activated mercury, than in the case of "La Bruja", in such a way that it has been necessary to amplify the vertical scale of the graphic.

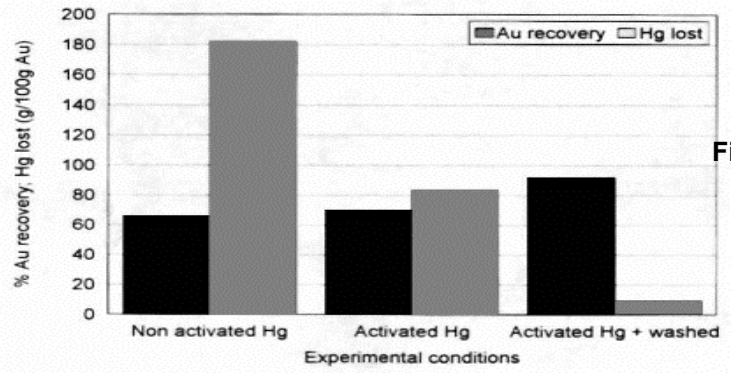

Figure 4

It non optimum conditions are used, as for example an excessive time of 4 hours (for the same quantity of mercury 3 kg/t), recovery of gold decreases and lost of mercury increases, as the Figure 5 shows. The scale of lost has been expressed in g per each 10 g of produced gold in order to get an adequate height of the bars. In this case, for activated mercury and previous washing of mineral, lost of mercury is 31 g per each 100 g of produced gold, that is, it has been multiplied by 3,6 times comparing with optimum time. Also the recovery of gold has been lower passing from 92 % to 86 %, approximately.

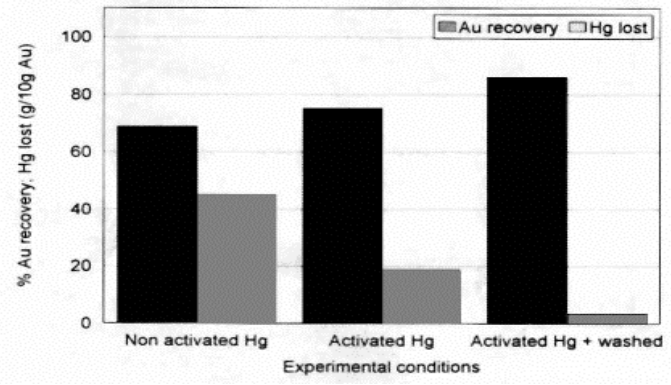

Figure 5

In the same way, the use of inappropriate quantities of mercury leads to worst results. Thus, if just 2 kg/t are used in the optimum time of 2 hours, results are shown in Figure 6, where it can be see a fall of recovery of gold, while lost of mercury are high (minor

than with 4 hours, Figure 5, but higher than optimum conditions, Figure 4). Therefore, with previous washing of mineral and activated mercury, mercury lost are of 29 g per each 100 g of produced gold.

The most of the lost of mercury is produced with solid rests; they are the main potential source of pollution by mercury for future and they will demand an adequate deposition or a treatment, in many cases impossible to be done by the small miners. To investigate the possibility of reducing this contaminant fact, preconcentration of gold has been tested in a Wilfley Table, known and reliable equipment that can works with electric or hydraulic energy, because it requires a lower power.

In essays done with milled minerals in less than 0,25 mm the simplified results shown in Table 4 have been got. They have used a stage of hewing and another of trimming which produce a concentrate of lower weight and a very high sterling that could be benefited by direct fusion and a second concentrate which is that one treated by amalgamation.

Table 4. Wifley Shaking Table Preconcentracion

FRACTION	"LA BRUJA"				
	WEIGHT (%)	ASSAY (g/t)		RECOVERY (%)	
		Au	Ag	Au	Ag
1° CONCENTRATE	0,11	88,885	25,877	32,21	14,45
2° CONCENTRATE	28,22	623,20	368	63,54	52,74
TAILINGS	71,67	17,96	90,12	4,25	32,81
TOTAL	100	303	197	100	100
FRACTION	"LA GRUESA"				
	WEIGHT (%)	ASSAY (g/t)		RECOVERY (%)	
		Au	Ag	Au	Ag
1° CONCENTRATE	0,04	22,594	8,256	20,75	2,55
2° CONCENTRATE	16,69	164	306	62,86	39,46
TAILINGS	83,27	8,57	90,10	16,39	57,99
TOTAL	100	43,50	130	100	100

It has seen how the rendition and the recovery of gold in preconcentrates is high, mainly in "La Bruja" case, due to its higher initial riches and it is possible to see how the quality of solids have been reduced considerably.

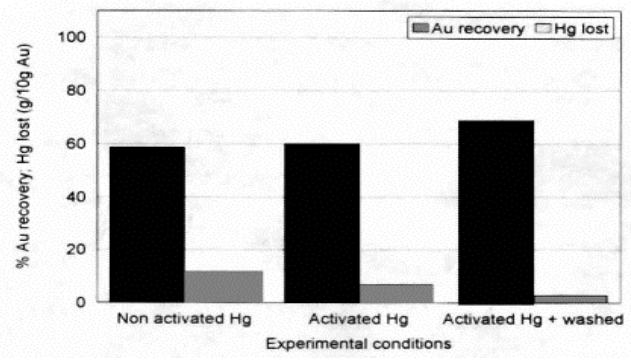

Figure 6

In “La Bruja” case the sum of the two concentrates reaches a 95,75 % of recovery. In “La Gruesa” case it reaches a 83,61 %. In the first case recovery is higher than in direct amalgamation but in the second it is lower. The second concentrates of both minerals have been amalgamated using the three variants of normal mercury without activating, activated mercury and previous washing of mineral and activated mercury. The results are given in Figures 7 and 8 for “La Bruja” and “La Gruesa” respectively, being recoveries in optimum conditions of 97,82 % and 97,42 % respectively, that means very good recoveries in this phase of amalgamation. Taking into account the global process concentration–amalgamation recoveries lay in 94,37 % and 82 % respectively, being similar the recovery to the direct amalgamation for mineral from “La Bruja” and lower for mineral from “La Gruesa”, and therefore in this last case the preconcentration would not be well accepted by miners.

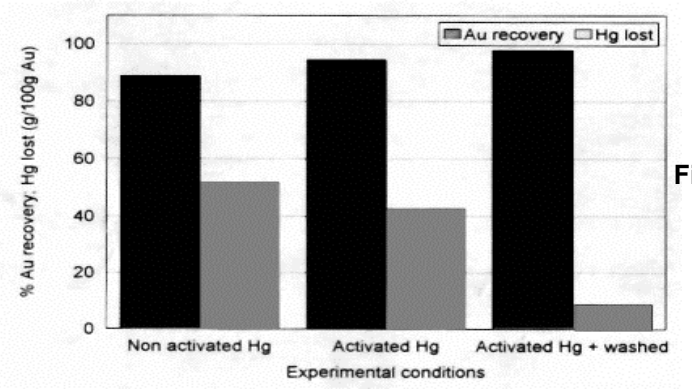

Figure 7

The mercury lost, in optimum conditions, are from 8,5 g and 15 g of mercury per each 100 g of produced gold in amalgamation, and if we have into the account the recovery gold in the first concentrates the results would be of 5,6 g and 11,3 g of mercury respectively, for each 100 g of produced gold because they are of the same order approximately than in direct amalgamation, but they are content in a lower volume of solids, that would be a 28 % of initial in “La Bruja” case and a 17 % in “La Gruesa” case, which would make easy its control.

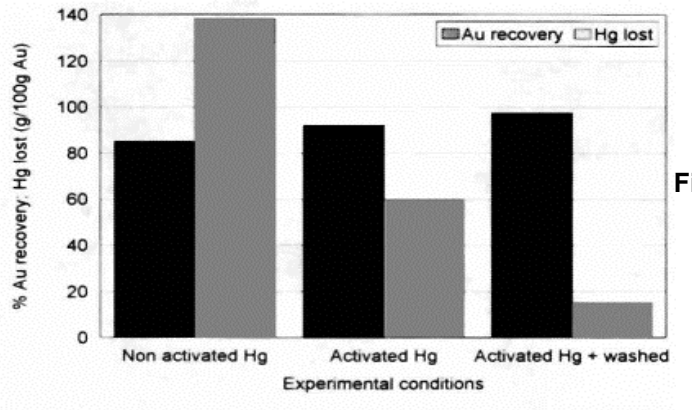

Figure 8

In the same way, by doing a balance of the advantages of concentrates amalgamation coming from gravimetry it must be considered that investments and expenses of production are lower than the whole mineral is processed due to the reduction

of mass to be treated. Versatility and simplicity of combination of gravimetric concentration methods in a table for shaking, barrel amalgamation and direct fusion, added to its lower cost and great efficacy make that this system can be taken into account at the moment of planning an exploitation, especially because of the reduction of volume of polluted material and that it must be essayed in order to determine results that can be waited and its profit or convenience.

Flotation as a possible preconcentrator process has been researched, although it could be a technique which implies greater investment and greater knowledge. In the case of direct flotation over original minerals after milling at 0,125 mm, recoveries in both cases are of 91 %, lower than direct amalgamation, although the mass of concentrates is reduced to 8 %–9 % of the initial mass, which is an indubitable ecological advantage.

Flotation of tailings of the concentration table, after milling at less than 0,125 mm gets a concentrate that it could produce an increasing of recovery of gold of 2,5 points in "La Bruja" case and of 11,49 points in "La Gruesa" case, which makes of the gravimetric concentration and flotation improves recoveries of concentration on an isolated table and allows an important reduction of volume of polluted solids, due to the volume of the flotation concentrate is very small compared to the table one.

CONCLUSIONS

In amalgamation process mercury electrolitically treated through using a simple equipment named "mercury activator" produces best results than normal mercury increasing the recovery of gold and decreasing lost gold and therefore, decreasing pollution.

The fulfilment of a simple operation of "previous washing" of mineral with detergent and alkalis, before the amalgamation stage reduces ostensibly lost of mercury and increases notably recovery of gold.

An optimum dose of mercury and an optimum time of treatment, easily deducted by experimentation, lead to decreasing of lost of mercury and gold.

A gravimetric concentration previous to amalgamation process reduces the quantity of material to be processed and therefor e the quantity of polluted by mercury rests, whose treatment and deposition are much more easy and of lower cost than the handling of sterile things result of amalgamation of neat mineral. In each case it must be study its viability and convenience.

Amalgamation of table concentrates in barrel with activated mercury and previous washing, combined with and adequate dose of reactive (Hg) and an optimum time of treatment, produces a recovery of gold almost whole, that must be corrected by recovery got en gravimetric concentration, which turns is the controller of the global process.

Concentration on table followed by flotation of rests and amalgamation lead to good results but is a technical complicated system that demands greater investments and higher costs of operation. Therefore its possible application is doubtful in small mining.

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IMPORTANCE OF THE CLOSING OF MINES IN THE EXPLOTATIONS OF VEIN GOLD IN COLOMBIA - GREEN GOLD FOR THE SUSTAINABLE DEVELOPMENT

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1. INTRODUCTION

Colombia has an important tradition in the gold production, that goes back to pre-Columbian times. The conquest in this country on the part of the Spaniards, was impelled to a large extent by the myth of " Gilded ", who listened to speak mainly of the treasure in the diverse regions and in Guatavita, although this myth we also found it related to other regions of the country where the main indigenous cultures were located.

The development of the mining in indigenoys epoch was on small scale, the natives used gold for its jewels and also it was importantin their religious rituals, the impact to the environment caused by the extraction of gold in that period was very slight. The environmental impacts of the indigenous cultures, though very serious that were, did not happen to represent local or regional effects around their own civilizations.

The society evolved and is as well as the establishment of another scale of values causes that this precious metal is a symbol of wealth, there are discovered important properties such as that it is a good conductor of electricity and heat, its malleability and ductility. All this did that the mining of gold, will be developed on a great scale and without considering the environmental impact that was generated by the mining explotations.

The studies made by organizations of the Colombian State as the INGEOMINAS maintains that Colombia has a high geologic-mining potential all over its territory and it is due to which good part of the economic history of the country, has depended in greater or smaller proportion of the mineral operation, specially of gold.

The resources are exhausted, the environment is contaminated; the modern development is threatening the total order of the life and is then when there is to raise the sustainable development in the activities that the man executes, a change process in which the use of the resources, the direction of the investments, the direction of the technological development and the management of the institutions must objectively take care of the human necessities of the present and the future. With the sustainable development it is tried to give a turn to the development concept, trying to conciliate the economic growth with the quality of life of the towns, with the social welfare and the preservation of the environment.

The gold is a resource, whose sustainable operation it can generate social wealth with environmental responsibility, becoming this way the auriferous potential of the country a source of development for the communities that live in regions where this metal abounds.

The sustainable operation of the mining must contain as a last fundamental step an adapted *closing of mines*, later to make of course, the previous steps in a project of mining exploration as there are those of prospection and exploration, planning and assembly, explotation, processing and metallurgical extraction of gold.

In this work important elements are contributed that they can be taken to the practice and thus to be able to operate in a rational way this gift that has offered nature to

us and to have the pride to say that *green gold* for the development of our society is being extracted.

2. THE GOLD IN COLOMBIA

In Colombia which calculates that in the present century approximately 850 ton of gold have been extracted, it does represent more than 50% of the total production in the country through history; production that has responded to the national and international price directly. The macroeconomic importance of gold in Colombia is appraised specially in its participation within the exports and the amount of the international reserves in which they are represented.

Until the Sixties, the extraction of the metal in Colombia was made fundamentally by great companies, within which they excelled those of foreign property. This panorama has changed radically, inasmuch as the small and medium producers come registering a participation flood.

At the present time, Colombia is including between the ten main producers in the world-wide scope, and is the second of Latin America after Brazil. The main exploitation system is the alluvial one, that in 1991 contributed 78 % of the production, measured by the purchases of the Bank of the Republic; the rest was originated in the vein mines.

2.1 Deposits Of Vein Gold

In Table 1 the main auriferous regions of vein mining appear, that is worth to stand out is operated in its majority by methods of underground mining.

Table 1. Gold mining districts of vein gold in Colombia

Regions	Districts
Easterm zone of Antioquia	Zaragoza-Segovia – Remedios Puerto Berrío
Central zone of Antioquia	Murindó Tiribibí Acandí (Chocó)
Western zone mountain	Batolito de Mandé Desert of Frontino Plateado Torrá – Tamaná Cumbitara - Piedrancha
Zone Ibagué - Sonsón	Ibagué Sonsón The Hatillo – Florencia Cajamarca-Salento-The Salitre
Zone Cauca - Romeral	Buga - The Retiro (Valle) Almaguer Marmato- Caramanta (Caldas)
Zone of the South of Bolívar (Mountainous area of San Lucas y Montecristo)	Río Viejo San Martín of Loba Barranco of Loba Montecristo Santa Rosa of the South Morales
Zone Desert of Santander	Vetas - California

2.2 Vein Gold Explotations In Colombia

In Colombia explotations of informal type made by the barequeros are made, they are groups of miners who work tunnels of little dimension or which they extract material of vein of tunnels already left by other companies. Also the formal mining made by the companies of small and medium mining of gold is made. The operation method that is carried out in these companies can define as a variation of the traditional method of rooms and pillars.

The metallurgical extraction of gold is made in spaces located near the zone of operation, or in the municipal heads; generally involves some of the following operations:

- Classification
- Crushing
- Milling
- Concentration
- Amalgamation
- Leaching with cyanide
- Smelting and purification

3. THE ORIGINATED ENVIRONMENTAL PROBLEM IN THE VEIN GOLD MINES

The auriferous mining affects the natural resources like the water, grounds, the fauna and the flora. The main environmental problems of the mining of gold are related to the situation of unmannerliness of the explotation, and the inadequate handling and environmental planning of the same ones.

In Colombia, including in the active life of a mine, diverse problems are being generated to the environment such as the collapse of the tunnels (subsidence), generation of the acid rock mine drainage, insuitable waste disposal, change in the run-off and underground waters, in the others. The dimension of this problems is greater when the owners decide to abandon the enterprise for a motives diferent to the deposits finished, it´s very commun in the small mining for lacking of a mine planing and a capital for to invest.

The pouring of the acid drainage of the heavy metal mine, rich, and the solid remainders which they are in waste areas of the mine, which they are remainders with effluents of the process of cyaniding and amalgamation and of the sterile ones of the mine, become activities that alter the water obstacles, because they are drainages that arrive at the water obstacles without before neutralizing them.

Physical-chemistries and biótics of the water change to the characteristics, the result is then, cloudy waters nonapt for human consumption or animal, in addition to the alteration of the ecosystem due to the diminution of present oxygen in the water, to the obstruction of the rivers and bogs, and to the difficulties in the development of the aquatic fauna. A negative impact is generated therefore on the productivity of the aquatic ecosystems, directly affecting the base of subsistence of the communities of fishermen.

4. IMPORTANCE OF THE CLOSING OF MINES

The explotations that are made in the mining of vein gold, in their majority are carried out by empirical methods, without no quantification of gold reserves and only by means of superficial geologic recognitions. The explotations are effected without mining planning and with rudimentary techniques of extraction. Lack planning, suitable technical

methods and the technology that is had is not the adapted one, the methods are still very manual. As a result it has a low productivity, the investments are low and limited, that is to say, it is expensive in economic and environmental terms.

Before this panorama it is necessary that besides to legislate itself a control in the environmental part of the mining by means of a system of environmental monitored with the participation of the local authorities exists, mining companies and local communities, so that therefore can be fulfilled what the Code of Mines of Colombia says that prohangs by the conservation of the environment by means of mechanisms such as:

- Exigency of the Environmental License.
- Monitoring and control of the form as it is made the use, conservation and restoration of the natural resources.
- Referring coordination with the environmental authority for the expedition of norms, instructions and orders to the environmental part of the mining.

The mining is a necessary activity for the development of any society, nevertheless the environmental deterioration that causes its controlled execution has not lead to that a social and legal exigency settles down to recover and to diminish the environmental impacts.

Environmental exigencies and fulfillments in all the passages of a mining project and in special must exist in the related thing to an adapted closing of a mine in such a way that the environmental damage can be recovered and be compensated that can have been generated.

In Figure 1, a model of operation of the mining cycle appears which must include a suitable closing of mine to avoid the aggression with the nature. After coming to extract the mineral resource, a later restoration is due to have and a series of environmental measures is due to execute, because otherwise these lands will be left in a situation of degradation without advantage possibilities.

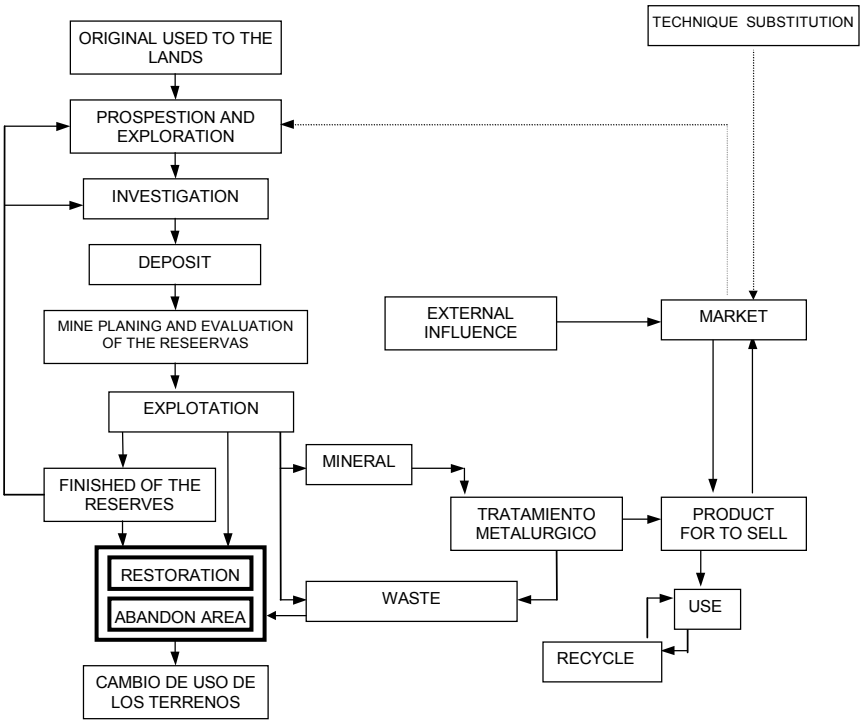

Figure 1 – Model of the operation to the mining cycle

A suitable plan of closing or abandonment of mining activities must contemplate the following aspects:

- Annexed supervision of the dismantling and activities
- Suitable evaluation and approval of works and activities of environmental restoration
- Final evaluation, identification of residual and alternative effects of solution
- Preparation and sustenance of all the information even the environmental design of the project and authorities

5. Aspects To Contemplate In A Closing Of Mines

5.1 Closing of Accesses

Once closed the mine it must be coming to its sealing by means of the construction of docks or bandage of closing of mine entrances and mouths diagonals or drums, with sufficient security and durability. The seal to place must prevent the oxygen entrance, of such form that prevents the formation of acid drainages of the mine. The seal must be of low permeability, like grounds of fine texture, the synthetic clays or slime, or materials.

5.2 Control of Effluents Liquids

It is made with the objective to avoid the pouring of residual waters of the mining to the environment without no previous processing and thus to prevent the superficial water contamination by residual and underground water pourings. One is due to carry out in the phase of dismantling of the mine.

With a good control of effluents the alteration of the physical and chemical quality of the water of the receiving bodies in the related a is avoided: pH, dissolved, mineral solids dissolved and solid suspended.

In the mining of vein gold, the gold is associated to sulphides and acid drainages of mine form, which are generated by the exhibition of sulfhides, mainly pyrite, to the air and the water; giving like result the production of acidity and high metal concentrations and sulfur. When the formation of acid drainage of the mine exists it is necessary to apply a neutralization technique, the used and more applicable technique is the lime addition, by its low cost and efficiency. This technique is made in five stages of processing: the homogenization, the mixture, the ventilation, the sedimentation and the final disposition of the remainder mud.

Also it is necessary to control the liquid effluents the solids in suspension that increase the turbidity of receiving waters, alternating the ecosystems. For the processing of solids in suspension of the mining drainage, sedimentations to gravity by means of the temporary storage of the water set out. These wells, tanks or lagoons of sedimentation must have a low speed of flow that allow the sedimentation of solids in suspension.

The processing of dissolved solids and the stabilization of pH, are managed by means of the ventilation of the mining drainage to favor the oxidation, this can be obtained making the water run through slopes by means of artificial cascades, with limestone rock beds of different sizes, for the stabilization of pH.

Another aspect to have is the fracture faults or on the rock induced by the mining that penetration sites allow that the underground or phreatic waters find footpaths, presenting towards the mine and becoming mechanisms of particle transport in suspension, of heavy metals, sulfur and of some metallic ions. It is very important then to characterize the deposit previously to be able to predict if the acid drainages of the mine will form.

The control of liquid effluents contain the processing and final pouring of mining remainders, it is due to disassemble and to close the mechanical systems of drainage and by gravity, except the constructed ones for the run-off water handling. The waste area of sterile must tell on a system of harvesting and processing of the run-off waters that have entered in contact with them, before being spilled to a water body or to infiltrate it in the ground.

He is recommendable which the waters that have journeyed on sterile materials and the originating ones of mining drainages are intercepted and lead to systems of processing by means of waterproofed channels.

All these workings of closing of mines must be in charge of the person in charge of the operation contract. The technical attendance and pursuit of the development of these activities must be in charge of the environmental authority.

5.3 Control of The Subsidence

The extraction of minerals and rocks of the terrestrial crust by underground workings potentially causes movements of the land and deformations of the surface, that is known with the subsidence name.

The operation method that is made in the gold explotations in Colombia is the one of rooms and pillars, with some modifications. This method indeed causes the phenomenon of the subsidence, more if it considers that the workings of the small mining are developed less than 50 m of depth and to this depth important implications in the stability of slopes are had. The underground excavations of the type of rooms and pillars collapse of

unpredictable ways. Exceptionally works located to more than 150 m of depth can produce collapses, causing damages to the superficial structures. The main mechanisms of deterioration and collapse of these underground works are three:

- Swelling of the floor

- Crushing of pillars

- Collapse of the ceiling

From the environmental point of view, the importance of the mining collapses is bound to three main factors:

- The extension of the affected surface

- The present and future use of the land in the affected area

- Type of magnitude of the movement of the land

In the mining explotations the pack one is due to consider, to diminish the magnitude of the vertical displacement, also it is due to try to make partial or harmonic an extraction. In the sites where they are detected superficial cracks some technique of sealing or cap is due to use which it can use the material of the slime or clays, impermeable or geotextiles fabrics, gravel and the slime. For the collapses in chimney form, produced by the technique of cameras and pillars, closings in form of pyramid or inverted cone will be able to be used.

5.4 Waste Area Adjustment

It consists of the adjustment of slopes and slopes of the waste areas of and the solid effluents of metallurgical process of extraction making the reforestation workings and thus to integrate the waste area from sterile to the natural landscape of the area.

With the adjustment of the waste areas the permanence of this type of land in the landscape of the zone is avoided, causing a positive visual impact, also prevent the slidings and landslides of sterile material to leached adjacent lands and something very important are that the formation is prepared with, that in case of forming could transport contents of zone.

The slopes must have a suitable height, according to the type of material and must be contemplated to the rectification and reconstruction of channels of water harvesting rains.

All waste area of sterile must be located far from all source or water body, as minimum 30 m of the border of any type of channel, continuous or intermittent and consider hydrologic the conditions local. Its location must obtain that any observer sees the smaller amount of rubbish throughout slopes, avoiding preferably the vertical rubbish accumulation, must consider that exposes the smaller possible area to the predominant direction of the wind.

The capacity of the produced waste area must so be that the total of the sterile ones is handled, allowing the suitable drainage of run off waters and causing the smaller visual impact. The escombrera must guarantee the stability with suitable geometry, constructing around its crown and leg the harvesting channels, conduction of waters of run-offs.

Figure 2 displays the sequence that is due to make when it is tried to remodel an already constructed waste area distributing its volume on a greater surface, will have to

retire previously to the existing vegetal earth on the land to occupy, with the purpose of having a base of more resistant support and of the necessary material for the covering and reforestation.

5.5 Reforestation

The objective of this activity is to establish the vegetal cover in the waste areas of sterile.

The impacts that are avoided with this are the following ones:

- Drag solids by run-off waters
- Cracking and later slidings of sterile material
- Negative visual impact
- Alteration of the properties physical-chemistries of water bodies

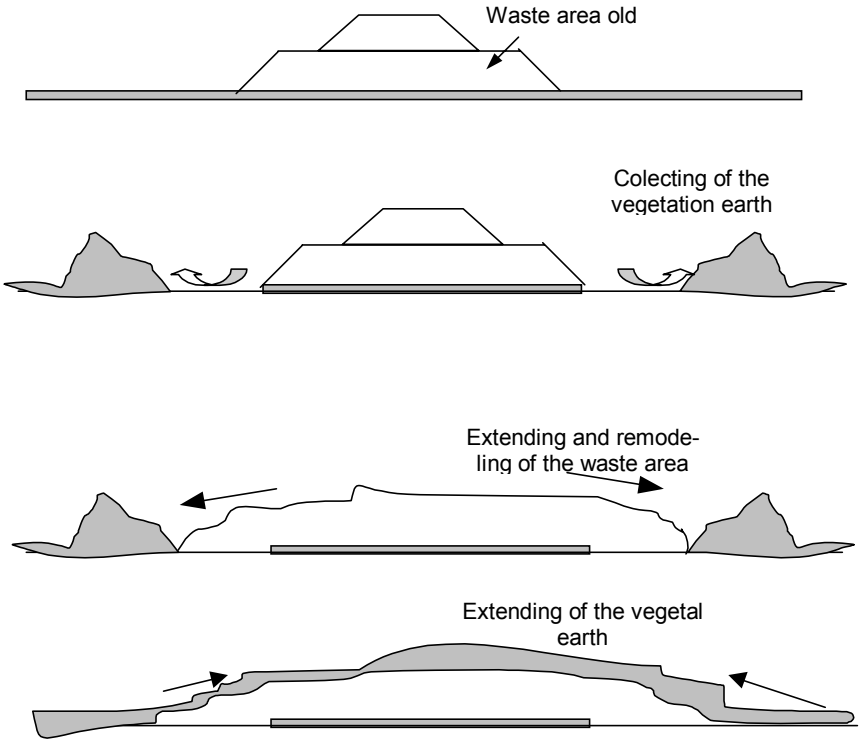

Figure 2 – Phases or the remodeling and the covering with the vegetal earth of the waste area old

The activities to develop in the closing of mine would be the adjustment of the land and relaxation of vegetal layer, sowing of seeds with native species of the region, fertilization and continuous irrigation, during the first three months of growth.

5.6 Protective Reforestation

It consists of seeding native arboreal species, for the long term establishment of protective forests of the hydric resource, and the habitat of the fauna.

It is tried to avoid the hydric erosion of grounds, the definitive loss of springs and water births and the definitive migration of some species of mammals and birds.

Native seeds of arbustivas species of the region are due to seed species, to prepare the land, to seed, with protective characteristics of channels of water and habitat of birds.

6. CONCLUSIONS

The explotations in Colombia are interrupted more by socioeconomic conditions not because the gold in the deposit finishes. Despite it is necessary to implement the program of closing of mines to avoid the environmental contamination.

The mining is an important line in the development of a country, by nature causes a negative impact to the environment, the intention is to implement environmental remediaciones to diminish the impact to ecosystems that the explotations surround by gold.

Sufficient investigations and works exist written in our country on closing of mines, is the moment for beginning to apply them and to remove them from the shelves of the libraries and the offices from the environmental authority, to avoid the future deterioration that could be reached.

The environmental costs must be assumed like a long term investment that will offer us in a future, one better quality of life, similar to the one of our Colombian indigenous ancestors.

It is necessary to develop to the mining of gold with techniques and suitable technology, in such a way that they are framed in the sustainable development and thus to be able to reach to produce so yearned

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SAN GREGORIO PROJECT

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INTRODUCTION

"San Gregorio" project is an enterprising which has been taking place since the beginning of 1997 at República Oriental del Uruguay where gold deposit exploitation is carried out. It is located in the northeast of the country nearby "Minas de Corrales" city, Rivera. It dates from the first five years of the current decade when intending studies to make a fresh start were initiated to the exploitation of gold –bearing mineral in that area.

Gold detachment process from the rest of the minerals requires the employment of cyanide in the physical and chemical methods. The outcome from the processing gold plant which contains a high percentage of cyanide is stored in a damming named "Relaves Dam" (RD) .This outcome will remain there until the closing works are made once the project is finished. The project operations are bound to be taken at zero discharge to the environment because the liquid coming from the "Relaves Dam" is reinserted in the production circuit.

It is estimated a five- year period of deposit exploitation divided in three steps. Each of them is determined by a volume increase of the "RD" by means of elevating the dikes' crowning.

Cyanide storage in these confinement conditions represents a defilement risk for the underground. To prevent this situation, the recipient where the solution of cyanide is stored was covered with geo membranes increasing the precautions during its location, and at the same time to make sure the damming impermeability.

Nevertheless, a leakage of that dam may be registered which means that cyanide could get into the underground flow. Therefore, a constant revision of the leakage's quality is necessary to detect any presence of cyanide in the underground, evaluate whether the concentration of cyanide is within the average permitted as well as taking the correspondent measures in case the results obtained are not the ones expected.

At present, the revision is carried out through the analyses of water samples which are periodically done by control public organisim DINAMA (National Environmental Management which belongs to the "Ministerio de Vivienda , Ordenamiento Territorial y Medio Ambiente" and with the company that forwards this project by using kits and laboratory analyses.

Until now, only once the presence of cyanide has been detected in one of the wells which was quickly associated with a crack in the geo membrane that coated the RD.

Designing a revision network which adjust to the procedures needed to detect the minimum cyanide concentrations requires a wide range of studies (hydrologics, hydraulic, and hydrogeochemical) which allow us to describe the local underground flow.

Around August 1994 and May 1995, it was possible to create piezometric map using information from 28 existent wells. However, only five of them are currently preserved plus six new ones that were built in March, 2000. All of them are located around "RD" and "Fresh Water Dam". The latter damming is situated upstream from the former, both having a dike in common.

The underground flow was locally altered due to the above mentioned dams and this new dripping system is the matter in question.

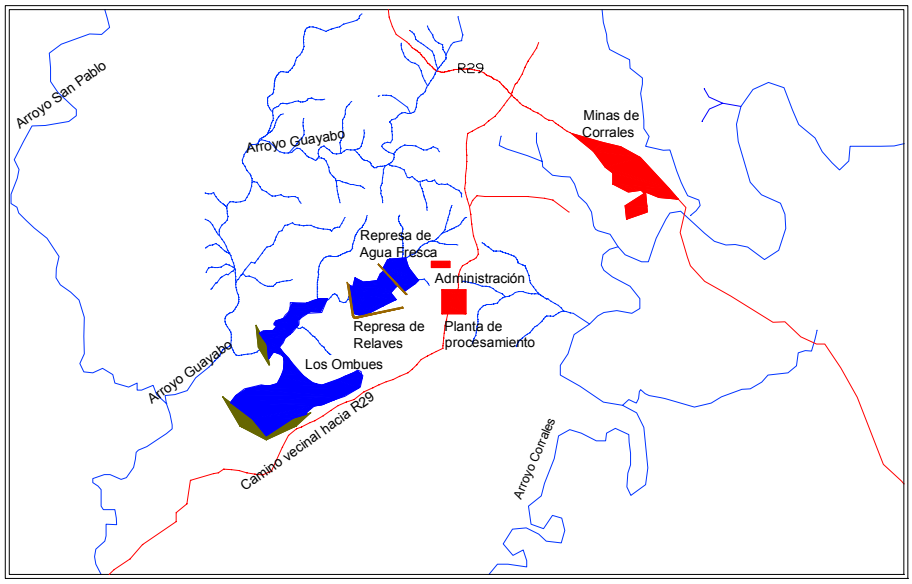
The local geology shows the presence of rocks which possibly suggest an underground flow through an interconnection fissure. According to the wells descriptions, there is a contact zone between the sedimentary source material and the main rock which is a greater aquiferous source than the fissured area.

The hydrologic model of the zone in question will allow us to establish the new wells location which will be incorporated to the network revision. In case any flow comes up, these new wells will assure the proper interception and sampling to detect a contaminant presence.

The study that is being carried out is an interesting matter to follow a preserving environmental policy . Nevertheless, the local characteristic of this study limits the resources available to complete all the tasks that need to be accomplished, but it also requires a precise measure when finished.

Project Description

The structure to exploit the gold-bearing mineral consists of an open air quarry, a processing plant for the removed material, and two dammings: one of them contains fresh water named Fresh Water Dam and, the other contains the discharge of the solid and liquid residues which is the result of the mineral treatment, and is denominated "Relaves Dam". The latter is located below and in a continual position from the former one. The location plant is found in the following plan:



LOCATION PLAN OF THE MINERAL ESTABLISHMENTS

The water for the industrial plant operation comes from the Fresh Water Dam. As the water and cyanide mixture is done during the minerals separation , the liquid with the processing material residues (1.36 density) is led to the Relaves Dam by means of tubes where solid residues deriving from the mineral treatment are discharged. The average

poured was estimated as 2500 tons per day. The amount of solid to store 3.75 millons of cubic metres which agrees with 5.10 millons tons of rock to be treated at the industrial plant during the project.

Below the membrane that covers the Relaves Dam is placed a drainage that registers the flowing water and leads it to a not very deep ditch but with a great diameter called Revision Well. The level of this well is constantly maintained by pumping a certain flow of the gully. It is situated downstream of the Relaves Dam and it is also coated with a geo membrane. Water samples are taken from this well which are analyzed at the laboratory. As the above mentioned well is the drainage receptor below the Relaves Dam , it was taken into account as the best place for samples to detect cyanide, and with the five wells reserved, it becomes the network revision that is currently used.

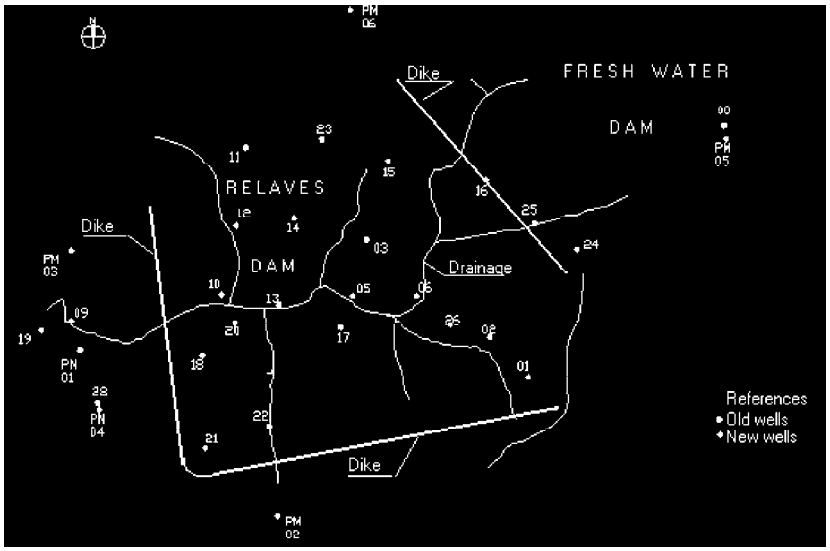
The Fresh Water Dam obstructs the watershed of 168 hás. It was foreseen a flood of 16 hás. The maximum deepness is of 7 metres and the maximum volume of water stored is 538.097 cubic metres.

The Relaves Dam occupies an area of 51 hás. The natural register watershed is of 238 hás from which 168 are obstructed by the Fresh Water Dam. According to the Engineering Project, besides the above mentioned measures, it must be added ,the necessary works to assure that the only contribution of water to the Relaves Dam (regardless the industrial process) comes from the direct pouring rain on the area intercepting another natural contribution by means of channels.

This dam contains a permanent water solution with cyanide with a concentration of 20mg/l , and the hydraulic charge varies according to the operation of it.

During all the damming operation, the dam would have a minimum of a sea room to retain a design storm that could give a water volume of 450.000 cubic metres (revenge 1.3metres)

The development of the project is carried out in three steps for the deposit exploitation which corresponds to the increasing capacity of the Relaves Dam. The elevation of this dam will reach its maximum height at the end of the third step. After each step is accomplished, the surface of the geo membrane is enlarged.



PLAN OF THE WELLS LOCATION.

Important aspects of the project

The underground area where this project is carried out is formed with sediments and splitting rock. The aquiferous is created where both sediments and splitting rock are touching each other.

Although the most important flow may take place in the porous area, it is necessary to identify the presence of a fissure system which could create ways of underground dripping of a logical magnitude

In terms of mineral establishments' construction, the location of the Fresh Water Dam up upstream which shares the same dike with the Relaves Dam, produces a dilution source when contaminant concentration is measures. This situation is increased in case samples are taken from the Revision Well.

Studies that have been carried out led mainly to determine the underground flow while identifying the respective proportion of the outcoming coming from the flirtation of Fresh Water Dam.

Within the preliminary studies, it was worked with monthly information of different parameters measured by the company as static level, pluviometry, temperature and water level in both dams. It has been intended to identify the connection between the wells and, indirectly, the fissures systems by means of the observation of the static level represented in the 28 wells and rains in the same period. The same goal was followed when Multi Varied Analyses Techniques were applied to the static level variations of the 28 wells. In that moment, it was concluded that two wells located in both extremes upstream and downstream from the ponds system had a similarity with the static levels. This might indicate an hydraulic connection between them, narrower than whichever other two wells that were nearer. The chemical analyses of the water samples carried out by the company gave the same results in terms of samples similarities ;except to the nitrates content which was different between one sample and another. This difference might be associated with some human activity nearby one of the wells that could imply this ion presence.

A calculation of the underground flow was done in the area of the studies starting from piezometric information of the 28 wells and estimations about the conductivity of the area. Such parameter will be adjusted through pumping rehearsals.

An hydrologic balance of the Fresh Water dam was put into practice to identify the flow received from the revision well. This flow is displayed in the balance within the loss flow from the Fresh Water Dam. It would get into the underground flow and it would modify it to such an extent that it will cause an important dilution in the water samples taken out to do the control of quality. The loss volume comes from the comparison between the monthly volume of that dam obtained by a hydrologic balance with the real volume that was in that month which was obtained by the measure of the water deepness in the damming and the height -volume curve of the recipient. Although is an estimated tool which may caused great errors for little gullies , it will be done a sensibility adjustment of each parameter. The calibration of this tool will be established by the comparison between the loss flow with the calculated flow by means of chemical substances between the Fresh Water Dam and the Revision Well

The feigning of splitting areas of the membrane are being carried out to assess the piezometric alteration of the area, and in consequence, the flow lines that were

affected by the construction of both dams. This would round up the studies to determine the right location of the new wells to extract and analyses samples.

Once the new revision network is established , a new flow model with a contamination leakage will be applied to check out the selection of the sample.

This task of statistics information management and parameters valuation is constantly accompanied with works in the site which generate data by means of static level measurements and extraction of samples to further analyses.

A sounding line was used to outline the drills from which electricity conductivity measures were taken. As it was easy to obtain information as well as its consistency in accordance with chemical analyses results, we are bound to develop this method as our tool to analyze the stem of the underground water.

It was possible to observe the underground material and locate the altered rock layer where is situated the underground dripping by building six new drills. Five drills were incorporated to our daily quality water study from which one of them was bent 60º to obtain ground samples

At the same time, we are looking for a water tracer which comes from Relaves Dam and which can be of simple evaluation. (sodium in the first instance) deriving from the cyanide of sodium added to the process. In terms of usefulness, the first analyses were encouraging, because, even though sodium is an ion which is within the components of underground water, its concentration at Relaves Dam is approximately 20 times larger. For this reason , we expect to be able to estimate the ionic exchange with the area at different places until we can achieve a revision drill as well as assess its use as a tracer in the hydrogeochemical study of water.

DRAWBACKS

Our main drawback is the assignment of interconnected splits (under sediment and rock contact) and its three -dimensional continuity, which is a matter commonly seen when investigations with limited possibilities to perforate are made while taking out ground samples .

CONCLUSIONS

In case a tracer which allows us to decide whether any cyanide contamination (water coming from Relaves Dam) has began to take place, an important stage will have been taken in the hydrogeochemical studies to describe the local underground flow.

A pumping and salinity rehearsals of wells that will be carried out next month, will allow us to obtain an appraisal of the prevailing flow zones.

Our final purpose, and obviously this study contribution is meant to achieve the finding of contamination in elementary investigations circumstances. In case this goal is achieved, the methodology limitations will have been overtaken which implies the lack of adequate resources in the environment preservation