

# **Mineral Processing Analysis in Artisanal Gold Mining, Peru**

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**Abstract** -The usage of inefficient techniques in artisanal gold mining is quite common, either to extract the ore or processing it, and related to environmental contamination. This paper analyse the mineral processing of a case study in Peru (San Cristobal) with the aim to improve the gold recovery process and the environmental impact. The process of amalgamation (gold-mercury) has been found as ineffective due to the presence of arsenic, while the particles size is not optimal to obtain the gold. Therefore the processing equipment should be changed to improve the grade recovery. The percentage of liberation particles and particle size distribution analysis are the key to evaluate the performance of the process.

**Keywords:** Gold recovering, Artisanal mining, Pollution, Mineral processing

## **1. Introduction**

There are between 10 and 15 million artisanal miners, mainly in Africa and Latin America, which are extracting an average of 350 tons of gold per year (Lacerda, 2003). Artisanal gold mining is widespread in Peru, where this activity is developed without any geological and technical knowledge.

This type of mining is used to employing inefficient procedures, like mercury and cyanide, to recover the gold, which are also very damaging for the health of the miners and the environment. In addition, the tailings generated are not adequately controlled and subsequently the population is exposed to high levels of pollutants (Cordy et al., 2011; Hilson and Van der Vorst, 2002).

The aim of this work is to assess the techniques used in the San Cristobal artisanal mining site (Peru), which will be necessary to improve the gold recovering process.

## **2. Methodology**

### **2. 1. Analytical Techniques**

Several samples in the different mineral processing stages were obtained. Besides, representative samples from the geological formation where the mine is places were taken.

In order to obtain faithful mineral grade, chemical analyses were performed at the Actlab laboratories, Canada, using FA-GRA and AR-ICP techniques. Particle size analyses were obtained in the sieve laboratory of the Department of Stratigraphy, Paleontology and Marine Geosciences at the University of Barcelona, using a Coulter Electronics LS230. For the mineralogical study, polished specimens were obtained and analyzed on a petrographic reflected light microscope Electrom microscopy (SEM) with a Tabletop Microscope Hitachi TM-1000 equipped with X ray Energy dispersive system (EDS) as well as using a SEM JSM-840 from the Scientific and Technical Services of the University of Barcelona.

### **2.2. Theoretical Fundamentals**

The Wigel (1976) and Gaudin (1939) approaches have been applied to determine the particle liberation, Eqs. (1) – (4). As there is little data related to the mineral processing and geology of the

deposit, it is considered that the method chosen match with what is demanded in the case study.

$$R_L > 1 \quad \mathcal{L} = \frac{[(R_L-1)^3 F_V] + [3(R_L-1)^2 F_V^2] + [3(R_L-1) F_V^4] + [F_V^8]}{[R_L^3]} \quad (1)$$

$$R_L < 1 \quad \mathcal{L} = 10 \left[ \left( \frac{1}{R_L} + 1 \right)^3 \log F_V \right] \quad (2)$$

$$L = \frac{\mathcal{L}}{F_V} \quad \left[ \frac{\text{kg liberated mineral}}{\text{kg mineral}} \right] \quad (3)$$

$$R_L = \frac{d_G}{d} \quad (4)$$

Where  $\mathcal{L}$  the particle liberation (%),  $d_G$  is the grain diameter before fracture,  $d$  is the particle diameter after comminution,  $F_V$  is the volumetric fraction of the ore and  $R_L$  is the comminution ratio.

In a binary system composed of two minerals, A and B, the volumetric fraction and the ore grade is determined by Eq. (5).

$$F_{V_A} = \frac{\frac{\text{Grade A}}{\text{density A}}}{\frac{\text{Grade A}}{\text{density A}} + \frac{1-\text{grade A}}{\text{density B}}} \quad \left[ \frac{\text{m}^3 \text{A}}{\text{m}^3 (\text{A+B})} \right] \quad (5)$$

Meanwhile Gupta (2006) detailed an equation the bond energy, which is showed in Eq. (6).

$$W = K \left( \frac{1}{\sqrt{D_1}} - \frac{1}{\sqrt{D_0}} \right) \quad (6)$$

Where  $W$  is Bond energy,  $D_0$  and  $D_1$  are the particle diameters before and after comminution and  $K$  is the work index depending on the type of material.

## 4. Results

### 4. 1. Ore Mineralogy

Mineralization in the deposit of San Cristobal occurs in veins related to granitic rocks. Ore minerals are mainly pyrite, chalcopyrite, arsenopyrite, sphalerite, galena, native bismuth, sulfosalts, electrum (Au-Ag amalgam) and native gold. Native gold is encapsulated in the pyrite matrix, while the second one is placed within the mineral fractures. In most cases, gold and electrum particles size ranges between 8 and 10  $\mu\text{m}$ , although they can reach up to 50  $\mu\text{m}$  (Fig. 1).

### 4. 2. Mineral Processing

The gold-bearing mineral is treated using two different comminution devices. Firstly, it is introduced into balls mill, where the grain size is substantially reduced from several centimetres to a few microns. Afterwards, the powder generated goes to a secondary milling process, using an artisanal mill, that consist in a mortar with a grinding stone made of granite. Here the powder is mixed with mercury to produce an Au-Hg amalgam. Later the produced amalgam is manually released from mixture by density difference properties. Then, this amalgam is burnt in open vessels or in a retort to separate the gold from mercury. This system allows to obtain a certain proportion of the gold enclosed in the mineral. Only the completely liberated particle can be amalgamated with mercury. Thus, the part dumped still has an important quantity

of gold and other elements like silver or copper. Therefore cyanide is applied to the tails to dissolve these elements and recover some of it by adsorption using activated carbon.

The grain size analysis of the ore after the secondary stage of milling indicates that D80 represents particles up to 200  $\mu\text{m}$ , while D35 represents particles up to 10  $\mu\text{m}$  (Fig. 2). The calculations of particle liberation point out that the ideal diameter for a D80 particle is 0.1  $\mu\text{m}$ . In terms of energy use, the power obtained by the grinding devices is approximately 13 kWh/t and the liberation of gold particles needs 115.03 kWh/t.

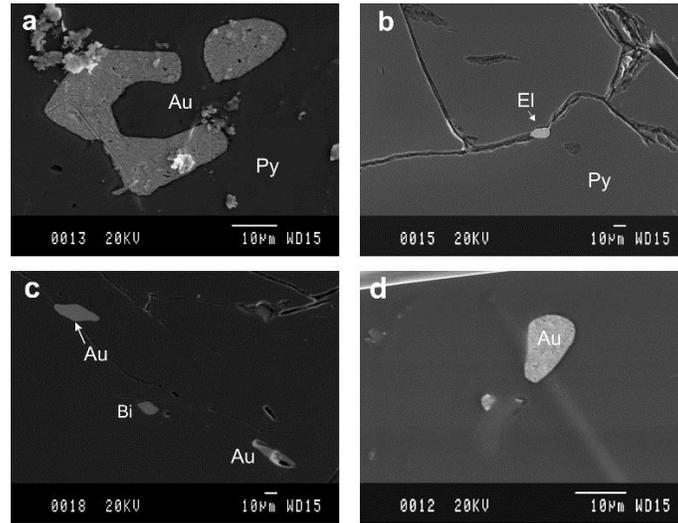


Fig. 1. SEM images from the San Cristobal ore showing the gold particles. Py, pyrite; au, native gold, El, electrum

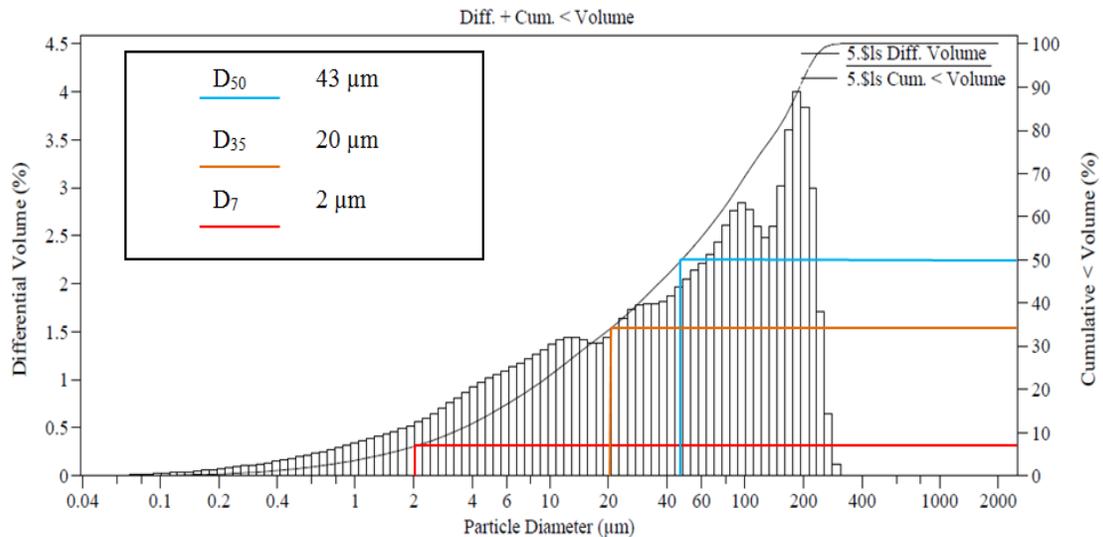


Fig. 2. Gold grain size distribution with the volume percentage and size

#### 4. 3. Chemistry of Materials

In the studied materials the San Cristobal deposit shows gold grade between 27 and 60 ppm Au. After the amalgamation treatment the gold grade is still remarkable, above 11 ppm (Table 1). On the other hand, the concentration after cyanidation of the tails drops considerably, between 1 and 19 ppm. In addition the mineralization usually shows between 100 to 200 ppm Ag.

The high concentrations of As in the samples due to the presence of sulfoarsenides in the deposit affect the effectiveness of the Hg added in the milling process to obtain the gold. Although mercury is

found in the original mineral, its proportion increases because of the amalgamation process. Sulphide minerals may be responsible for the high consumption of mercury amalgamation process. This phenomenon is especially important when arsenopyrite is found; therefore, arsenic has priority to react with mercury rather than gold (Wotruba, 2003). All samples display high Cu contents. More than 0.1 wt. %.

Table 1. Representative analyses of the metals concentration in different stages of the mineral processing in San Cristobal. Results are given in ppm.

Sample	Stage	Au	Ag	Hg	As
QU2	Original mineral	27.8	138	228	428
QU1	Post-amalgamation	11.1	175	589	472
QU3	Post-Cyanidation	1.33	57	6	291
SRC2	Original mineral	33.2	117	9	519
SRC1	Post-Cyanidation	18.5	176	917	434

#### 4. Conclusion

1. In the San Cristobal deposit native gold is encapsulated in a pyrite matrix, whereas electrum is placed within the fractures of pyrite.
2. The high consumption of mercury is caused by the presence of arsenopyrites with the gold ores.
3. The energy required to liberate the gold particles is 115.03 kWh/t, meanwhile the energy used is 13 kWh/t. Thus, the current equipment is clearly insufficient to work efficiently.
4. The analysis of the metals concentration shows that the cyanidation process has a higher degree of gold recovery than Hg amalgamation.

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