



## Effect of Organic Carbon on Gold Leach

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**Abstract:** Third gold producer in Africa, mining is a strategic industrial area for Republic of Mali. Major part of Malian gold production coming from gold mine industries, increase in the gold recovery will increase the national gold production. Deposits containing carbonaceous materials are a limiting factor, they have a considerable impact on recovery by stealing (robbing) the gold in solution (preg-robbing).

The first mineralogical analyses carried out show that the main mineral present in the sample is iron oxide; the most significant characteristic of the analysis is the absence of gold detected in the concentrate and the tailings of the concentrator. Interpretation of these results may be that the gold is in the form of invisible gold in both samples. Which indicates that gold has been preg-robbled by organic carbon.

This study aims is to evaluate the detrimental effect of organic carbon (Corg) on recovery and provide calcination process parameters to increase recovery at CIL.

The work reported in this paper show that by roasting, carbonaceous materials are oxidized, preg-robbing effect is reduced, and gold recovery is increased. Roasting in combination with a Carbon-In-Leach (CIL) circuit permit to increase gold recovery more than 50%. Test results show that calcining carbonaceous ore for 30 min at 700 – 750°C provides good organic carbon (Corg) removal of up to 91.1%. Thus, the recovery was 2.8% in average before calcination increased from 56.3% or a total of 59.1% after calcination. In other words, for each 100 t of tailings solids containing an average of 6.78 g/t of gold, after calcination, 401 g of gold are recovered by CIL leaching.

Size by size analysis has been performed on the initial CIL tails composite samples before leaching and on the calcined sample solid tails after leaching. This permeated to understand which portion of Au is liaised with Corg and in which proportion.

According to the results, 80% of the gold (in average) and 95% of the Corg (in average) are in the finest particle size class -38 microns in the solid tailings of the CIL, which explains the preg-robbing phenomenon of gold in solution caused by Corg (Ratio Au: Corg is 1:1) or unoxidized auriferous pyrite (76% pyretic sulfur). In terms of mass the Corg is 20 times more than the pyretic sulphur. After removal by calcination of 90% Corg and 30% pyretic sulfur in the -38microns class, 67% of the gold was leached in this fraction.

**Keywords:** Roasting, gold, organic carbon, preg-robbing.

### 1. INTRODUCTION

One of the major key performance indicators in the gold mining industry is recovery, which shows the effectiveness and efficiency of ore processing. Factors impacting gold recovery pose a challenge for gold mining industries. The deposits of carbonaceous materials are part of these factors. Ore sources that are easy to process are limited. Exploration activities involve several increasingly complex ore bodies and require innovative approaches in the extraction process [1,3]. One of the challenges in gold processing is the processing of ores with the Preg-Robbing (PR) effect.

Deposits which contain carbonaceous material are an example of complex ores and are considerate as refractory when gold extraction in a direct cyanidation process is less than 80% [1]. In other words, gold ore is refractory when the metal of interest cannot be optimally recovered by conventional

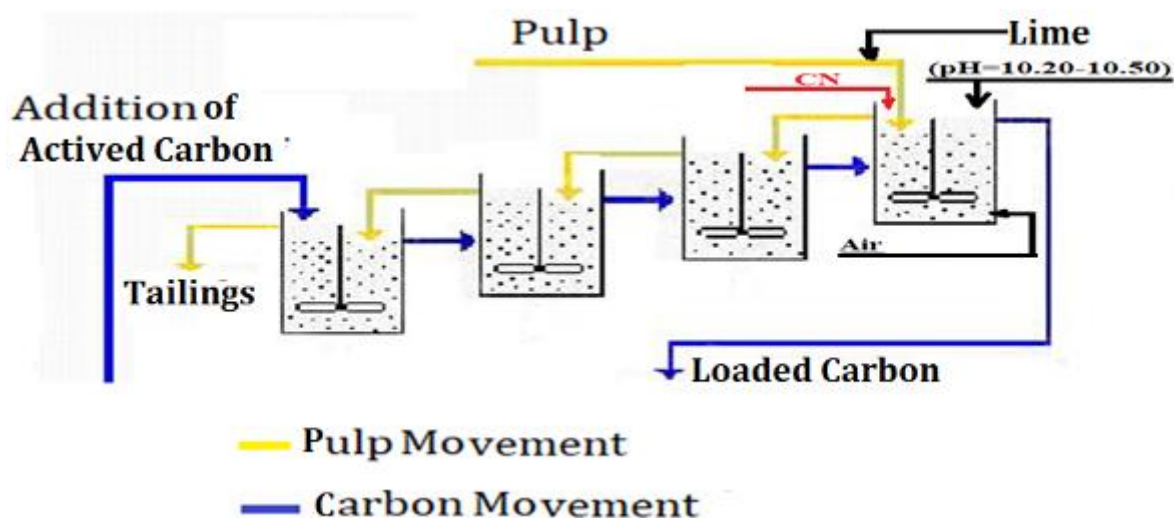
methods. These ores are commonly called preg-robbing (PR) as the Au cyanide complex  $[\text{Au}(\text{CN})_2]$  is “robbed” or adsorbed by the surface of carbonaceous material from the leach solution. They are commonly considered complex as the ultra-fine carbonaceous particles are not easily separated from the gold [2,3,4]. From the advent of the cyanide leaching process in 1880, the carbonaceous material present in gold deposits has been considered a significant cause of gold loss [5].

Hausen and Bucknam [6] stated that carbonaceous matter causes two types of difficulties. Firstly, the carbon can lock up a proportion of the gold in the ore and inhibit leaching. The carbon therefore acts in a refractory manner. The ore can also contain activated carbon that adsorbs gold from the pregnant solution. It therefore acts as an activated carbon. Flash chlorination is used to deactivate the carbonaceous properties of this ore [1].

Ore containing carbonaceous material can be classified in two groups [7,8,9,10]:

- a. Lowly and mildly preg-robbing ores: Carbonaceous ores with a total content of organic and graphitic carbon less than 1%. For gold extraction from them Carbon-In-Leach (CIL) process or pre-treatment of the ore with blinding agents to minimize the gold losses are used.
- b. Highly preg-robbing ores: containing more than 1% carbon with high tendency to adsorb gold. For gold extraction from them flotation, roasting and blanking or blinding are recommended.

Roasting is an effective way to oxidize carbonaceous materials and eliminate the PR problem, while Carbon-In-Leach (CIL) can improve gold recovery of mildly PR ores [11]. A CIL circuit is a process of continuous leaching of gold from ore to liquid and counter-current adsorption of gold from liquid to carbon particles in a series of tanks (figure 1). During the process gold is concentrated from ore on carbon. In this case due to PR effect, active carbon moves to the first tank of the circuit and will compete with carbonaceous material.



**Figure 1.** CIL tanks diagram in a gold extraction plant with carbonaceous ore

This work focuses on a study of PR in the common CIL process, as an alternative for efficient recovery of gold in carbonaceous ores. It has several industrial applications. During the calcination process, one of the key factors is the removal of carbon. The objective of this study is to evaluate the detrimental effect of organic carbon ( $C_{org}$ ) on the recovery and to provide calcination process parameters in order to increase the recovery at CIL.

## 2. MATERIAL AND METHODS

Information about the sample: The study was carried out on CIL tailings from the Syama gold mine, located in southern Mali. The sulphide circuit processes the ore coming from underground mining, the ore is double refractory, and this is linked to the gold encapsulated in the pyrite (Figure 2) and to a high content of organic carbon ( $C_{org}$ ) in the feed of the grinder down to 0.4%.

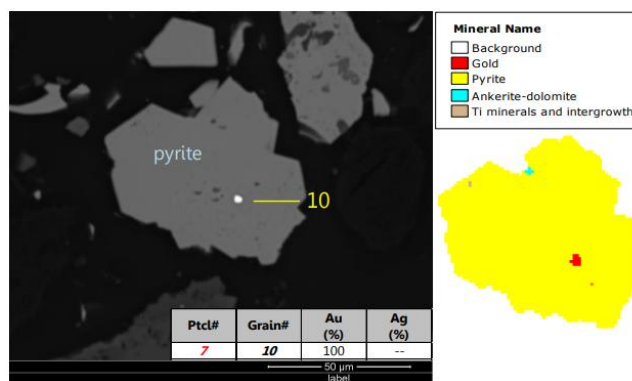


Figure2. Gold particle locked in the pyrite

Flotation concentrate is feeding Roaster to liberate gold by calcining sulphides and eliminate around 80% of Corg. Calcined material is quenched and send to the thickener to feed the CIL with 45-50% of solid.

The samples have been taken from the CIL tails. Sampling days were selected according to the plant daily recovery: when plant recoveries where lower. In total five samples have been collected for the test work.

Sample treatment: Samples have been filtered, due to samples were slurry samples, and dried in the oven at  $105 \pm 10$  degrees, for moisture elimination. The weight of each sample was determined and registered. Each sample was divided by two and extended leach has been performed on the first part of samples by using standard BRT (Bottle Rolling Test) to reproduce the treatment condition according to the residence time in the last leaching tank in the plant. The second part of the samples was roasted at  $700 - 750$  °C in 30 min interval time. Calcined ore has been leached. All leaching products (head solid, tails solid and solution, and active carbon) were submitted to the Laboratory to determine gold (solid and solution), Corg (solid) and sulphide sulphur (solid) (Figure 3).

Composite head sample was submitted for Mineralogy test, to determine presence of free leachable gold.

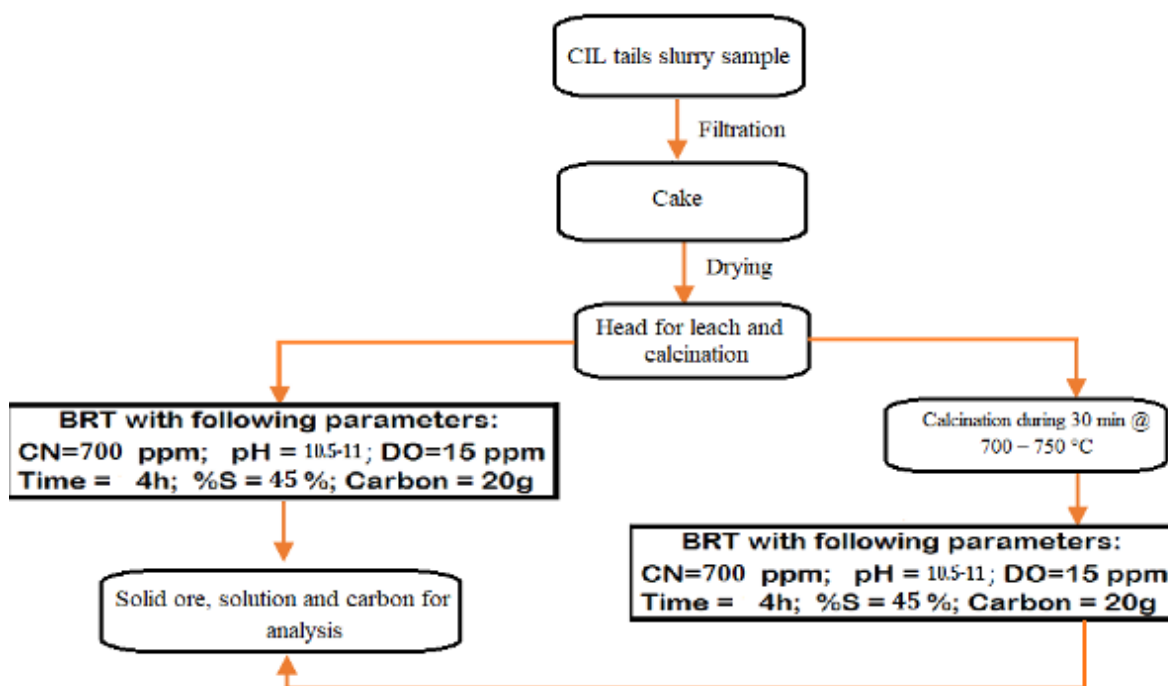


Figure3. Samples treatment scheme

## 2.1. Samples Preparation for BRT

500g of ore was used to prepare a pulp with 45 % of solid. Hydrated lime was weighted and add progressively till pH reach the target and the weight was recorded. Sodium cyanide 98% purity was used to obtain 700 ppm strength in the pulp. Dissolve oxygen was provided by using oxygen line installed in the laboratory. 5g of active carbon with 84% activity were added to recovery gold in solution. The bottle containing the prepared pulp have been posed on the rolling table for 4h leaching time [table 1]. After that active carbon recovered, by screening the pulp, as oversize of 1 mm screen aperture and samples were filtered to separate solid and solution. Head and tails solid size by size analysis has been performed as well.

**Table1.** BRT sample preparation

	Name	Cyanidation (pulp 45%S)						
		Time	solids	water	Carbon	lime	NaCN	PH
		(Hrs)	(g)	(ml)	g	(g)	(PPM)	
Extended Leach	Sample 1	4hrs	500	611	5	0.30	700.0	10.47
	Sample 2					0.35	700.0	10.50
	Sample 3					0.30	700.0	10.54
	Sample 4					0.37	700.0	10.63
	Sample 5					0.40	700.0	10.84
Calcination before leach	Calcined 1	4hrs	500	611	5	0.41	700.0	10.58
	Calcined 2					0.46	700.0	10.70
	Calcined 3					0.49	700.0	10.77
	Calcined 4					0.40	700.0	10.58
	Calcined 5					0.50	700.0	10.82

## 2.2. Methods of Analysis

Gold in solid was determined by flame atomic absorption (FAA). Method Code – FAA505, limits of detection - 0.01ppm.

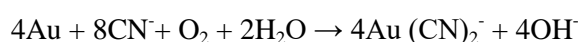
To determine carbon and sulphur in the sample, carbon methods and equipment include the LECO carbon-sulphur analyser and high temperature combustion infrared detection was used. During this procedure, the carbon in the sample is converted to carbon dioxide CO<sub>2</sub> and the sulphur in the sample is converted to sulphur dioxide (SO<sub>2</sub>), which are then measured by infrared (IR) detectors.[12]

- Organic carbon analysis: Method Code - CSA03V, limits of detection - 0.01%.
- Sulphur analysis: Method Code - CSA08V, Method - Various, limits of detection - 0.01%.
- Gold in solution was determined by AAS (Atomic Absorption Spectrometer) reading: Method Code - SOL81X, limits of detection - 0.001mg/L.
- Gold in active carbon was determined by scheme for the determination of Au in active carbon: Method Code - ARS12D, limits of detection - 0.001 ppm.
- HachHQ40D pH meter was used for the pH reading.
- HachHQ40D Portable Dissolved Oxygen Meter was used for the DO reading.
- Sizing was performed on the standard laboratory sieve series.
- Laboratory Knelson concentrator to separate CIL tails samples in pan concentrate and pan tails.
- Mineralogy for AMA (Advanced Measurement Approach) gold analysis has been performed on the head ore. The automated mineralogy analysis modes of measurement used particle Analysis with random particle selection for tail samples.

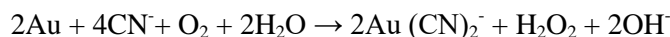
## 3. RESULTS AND DISCUSSION

### 3.1. Mechanism of Gold Dissolution

The mechanism of gold dissolution in cyanide was first studied by Elsner (1946) and the reaction is given as [13,14]:



The process of leaching gold from its host minerals by cyanidation is widely used in the minerals industry and in the major gold producing countries. A similar reaction for the dissolution of gold by cyanide is [15]:



This reaction, which is electrochemical in nature [16,17] shows that gold is oxidised in alkaline cyanide solutions to form the aurocyanide complex in the presence of oxygen. Aurocyanide, hydrogen peroxide and hydroxyl ions are also formed. The hydrogen peroxide formed can act as an oxidising agent for the further dissolution of gold, but more commonly this decomposes and takes no further part in gold leaching.

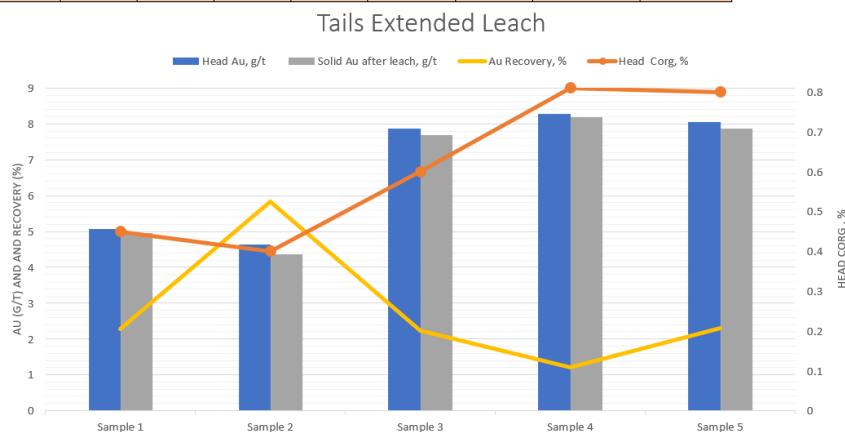
### 3.2. Direct Cyanide Leach of the CIL Tails

According to the results reported in the table 2, gold grade varied from 5.07 g/t to 8.29 g/t, and Corg from 0.4 % to 0.81%. Gold grade is directly proportional to the Corg grade in the sample. The Au:Corg ratio increasing when the Corg grade increasing, and the recovery drop down, that can be explain by the PR phenomena [ Figure 4].

According to the extended leach results in average gold recovery is 2.8%. Lower recovery was obtained with the sample with higher Corg contained (Corg = 0.81% and recovery 1.2%) in opposite higher gold recovered from the sample with lower Corg contained (Corg = 0.4% and recovery 5.8%). Lower Solution gold concentration and higher leach tails solid gold grade indicates poor kinetic of dissolution, gold is dissolved but adsorbed back to the solid phase or that the gold is not in leachable form in the sample, which can be resulting from the dicyanoaurate ion adsorption by the Corg. In other side active carbon lowly charged confirmed the low solution concentration value. 4 Hours extended leach resulted shows that the weak dissolution of gold is not related to the residence time, the CN concentration or D.O. (12-15 ppm during test work). The population of unoxidized gold bearing pyrite in the samples is represented by 0.094% in average (Sulphide sulphur grade from 0.06% to 0.13% [Table 2]) which is 940 g/t, can be where part of gold is encapsulated as well. The residual cyanide (cyanide consumption) was high in the tail’s solution around 600 ppm in average with 10.37 final pH in average. It shows that cyanide have not been consumed during the 4h for the leach. It was undertaken to calcine the CIL tails in order to eliminate the Corg and reconduct the cyanide leach test in the same conditions.

**Table2.** Test results

	Name	Assays					Corg elimination (%)	Gold Recovery (%)	
		Head Solid			Solution	Carbon			Tails Solid
		Au (g/t)	Corg (%)	S2-S (%)	Au (mg/L)	Au (g/t)			Au (g/t)
Extended Leach	Sample 1	5.07	0.45	0.12	0.0145	16.0	5.0	2.3	
	Sample 2	4.635	0.4	0.06	0.003	10.0	4.4	5.8	
	Sample 3	7.87	0.6	0.07	0.0215	2.0	7.7	2.2	
	Sample 4	8.285	0.81	0.13	0.0105	49.0	8.2	1.2	
	Sample 5	8.045	0.8	0.09	0.0235	50.5	7.9	2.3	
Calcination before leach	Calcined 1	5.10	0.05	0.02	0.018	220	2.5	88.9	
	Calcined 2	4.645	0.15	0.04	0.006	260	2.4	87.5	
	Calcined 3	7.87	0.05	0.05	0.046	1,080	3.0	91.7	
	Calcined 4	8.285	0.05	0.06	0.039	590	2.8	93.8	
	Calcined 5	8.05	0.05	0.03	0.063	440	2.5	93.8	



**Figure4.** Corg impact on the extended leach

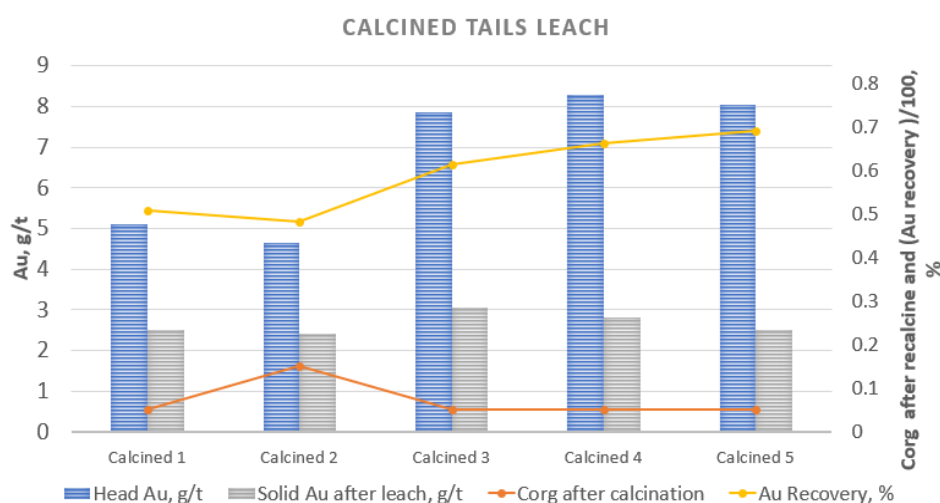
### 3.3. Cyanide Leach of the Calcined CIL Tails

The head material for the previous leach test was calcined during 30 min @ 700 – 750 °C and 4 hours extended leach was performed on it [Table 2]. Some of sample head grade increased after calcination that can be explained by the sample masse lost. Considerable Corg elimination factor was observed in average 91.1% Corg has been combusted from the samples (From 0.612% to 0.07%). Sample < calcined 2>, which initially was contained 0.4 % Corg, have the higher Corg value (0.15%), that can be related to the test conditions. It's interesting to note that sulphide sulphur was reduced by 0.054% in average (from 0.094% to 0.04%) which can be interpreted as increase in liberation of unoxidized gold bearing pyrite. The residual cyanide (cyanide consumption) was low in the tail's solution around 200 ppm in average with 10.3 final pH in average. It shows that cyanide have been consumed during the 4h for the leach.

Recoveries were varied from 48.1% to 68.9 % (59.1% in average) [Table 2]. This shows that the weak gold dissolution kinetics related to the Corg,unoxidized gold bearing pyrite contended in the tails solid or others mineral form which hampered dissolution. Au grades were dropped from 6.6 g/t (direct leach solid Au average grade) to 2.7 g/t (calcined solid tails average Au grade after leach). Activated carbon gold grade was considerable and was varied between 220 to 1080 ppm. This test shows that calcination by reduce Corg (unoxidized gold bearing pyrite) had a positive effect on the leach recovery by increasing it more than 50% in 4 hours' time. We observe an increase in recovery at the same time as the decrease in the level of Corg( Figure 5).

CIL Tails Composite mineralogy has been performed to see if there is a leachable gold presence.

Samples was treated in the Knelson separator to concentrate free leachable gold in the concentrate. And Mineral association data are created based on normalised to 100% transition numbers(~grain contacts length) created during particles scan. The data are illustrated in bar charts in figure 6 and 7. Relative to 100%, the columns emphasise the proportions of mineral associations for each individual mineral including surface exposure.



**Figure 5.** Calcined tails solid leach performance

Large Free Surface (grain % surface exposure ± liberation) ratio is an indication of good liberation of a particular mineral

- The CIL Tails Comp – Gravity Pan Tails modal data show the main mineral present in the sample is Fe Oxide. Aside from the Fe Oxide there is significant amount of Feldspar and Mica/Clay and minor amount of other silicates and carbonates. As to be expected no gold was detected in this sample [Figure 7].
- The modal data obtained for the CIL Tails – Gravity Pan Concentrate a high concentration of Fe Oxide and Monazite and minor Quartz and Ti Minerals. However, care needs to be taken in interpretation of this data as it is based on only a hand full of particles. However, the most significant feature of the modal data from this sample is the lack of any Gold detected in the concentrate. This result indicates either the Gold concentrate is too low and so the gold particles were missed during preparation, or the gold is in the form of invisible gold [Figure 6].

Size by size analysis has been performed on the initial CIL tails composite samples before leaching and on the calcined sample solid tails after leaching [figure 8]. This permitted to understand which portion of Au is liased with Corg and in which proportion.

According to the results 80 % (in average) of gold and 95 % (in average) of Corg are in the finer particle size -38 um in CIL tails solids which can be explained by the PRI phenomena causing by Corg (Ratio Au: Corg is 1:1) or unoxidized gold bearing pyrite (76% S-s). In term of mass Corg is 20 times more than S-s. After elimination of 90% of Corg (and 30% S-s) in -38 um (by calcination) 67% of gold were leached in this fraction.

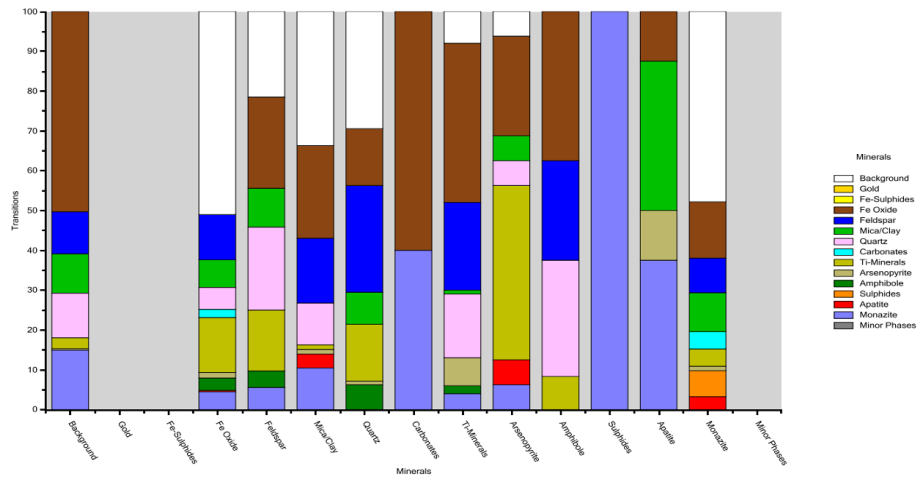


Figure6. Mineral association for CIL tails composite gravity pan concentrate

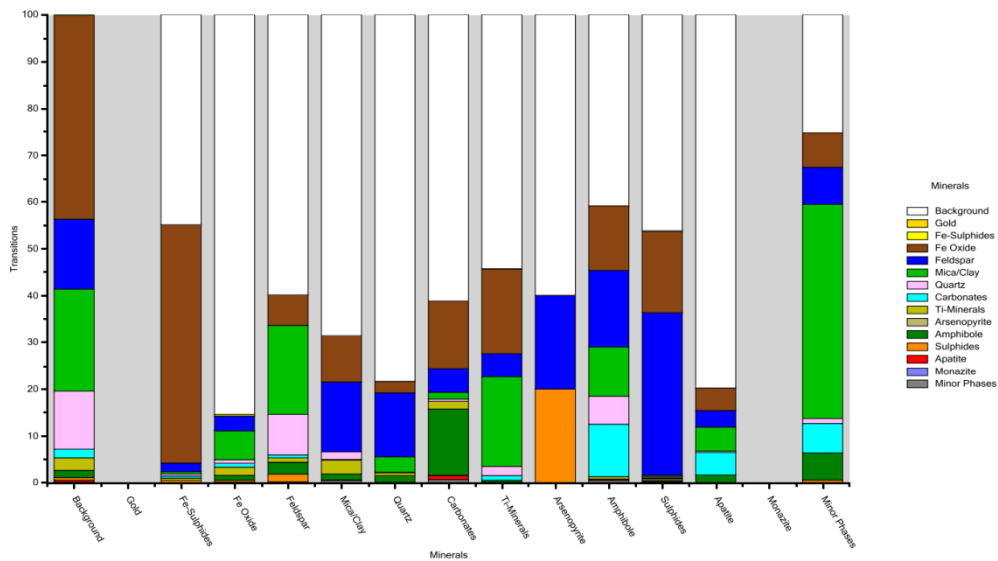


Figure7. Mineral association for CIL tails composite gravity pan tails

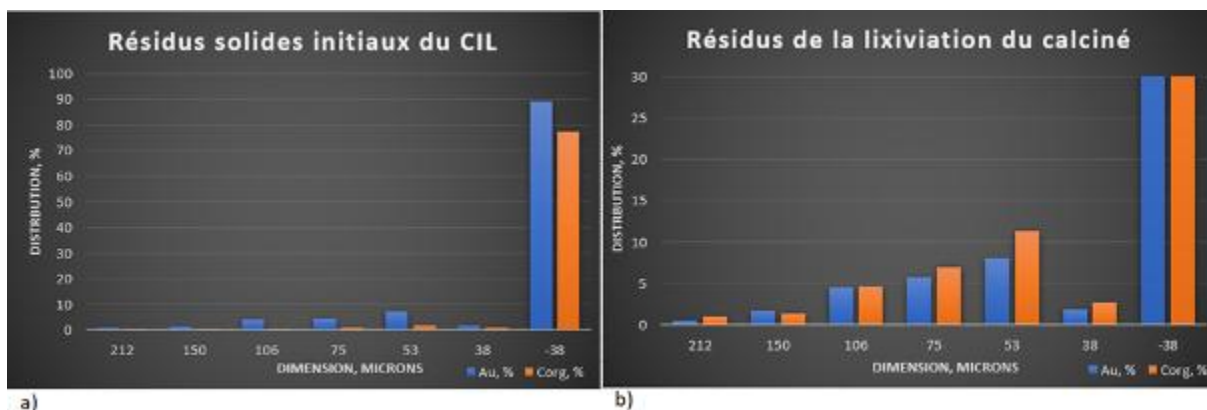


Figure8. Au vs Corg mass distribution in the a) initial CIL tails solid sample and b) calcined leach tails solid

### 4. CONCLUSION

Carbonaceous materials present a challenge for gold mining industries. The results confirm that roasting is an effective and efficient way to oxidize carbonaceous materials by considerably reducing gold preg-robbing phenomena. Calcination in combination with a CIL circuit maximizes gold recovery. Results of test work show that calcination for 30 min at 700 – 750°C provides good Corg removal of up to 91.1%. The recovery rate increased in average from 2.8% (before calcination) to 59.1% (after calcination). Thus, for each 100 t of CIL tailings solids containing an average of 6.78 g/t of gold, after calcination, 401 g of gold are recovered by CIL leaching. The first mineralogical analyses carried out show that the main mineral present in the sample is iron oxide, the most significant characteristic of the analysis is the absence of gold detected in the concentrate and the tailings of the concentrator. Interpretation of these results may be that the gold is in the form of invisible gold in both samples. Which indicates that gold has been preg-robbed by organic carbon.

The particle size analysis carried out on the composite samples of the initial CIL residues before leaching and on the solid residues of the calcined sample after leaching made it possible to understand in which fraction the gold is more in bond with Corg and in what proportion.

It is necessary to perform a BRT diagnosis on the solid residues of the CIL and to pulp them if necessary.

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