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Influence of Copper and Arsenic on Gold Recovery in the Yalea Deposit, Western Mali

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Abstract

Gold recovery process is well known. The following paper presents the problematic related to the influence of Copper and Arsenic on the recovery of gold in the Yalea deposit. Multielement tests (Au, Cu, As) carried out on 37 blocks made it possible to understand that there is a correlation between these elements. This correlation has been observed since the analysis of block models (the block model for Copper, block model for Arsenic and the block model for gold. These models have shown that the Yalea deposit areas with a high gold content correspond to areas of high copper content and arsenic. Those who made it clear that copper and Arsenic are tracing elements of Gold in the Yalea deposit. In this paper, the mineralurgical tests carried out on 28 blocks revealed that the copper and the arsenic content in the ore penalize the recovery of Gold (146 ppm for copper and 4710 ppm for Arsenic). The Yalea deposit was emplaced by several hydrothermal phases that reactivated the structures. These phases are responsible for the establishment of large quantities of copper sulphides. Copper and Arsenic are elements that have a considerable influence on the gold recovery in the Yalea deposit.

Keywords

Gold Recovery, Yalea Deposit, Mineralurgical Tests, Tracing Elements

1. Introduction

In Mali, gold export has substantially increased since the 1990s [1]. Copper and Arsenic show serious problems in gold ore processing if their content reaches a threshold.

Gold ore processing and all the technical processes used to extract gold from this ore, its recovery rarely reaches 100%.

However, all primary gold deposit in West Africa can be classified as orogenic type gold deposits [2]. West Africa suffers from artisanal and small-scale mining formalization problem as other mineral rich countries in the region [3]. According to the available information [4] [5] [6], there is limited research on gold resource in Mali. The purpose is to understand the gold recovery process. Recovery is one of the important parameters in mining; its weakness can lead to the cessation of exploitation. Despite its high gold content, Yalea and Syama ore is a refractory gold ore due to its mineralogical composition, which contains elements such as Cu and As [7].

2. Geological Setting

2.1. Regional Geology

2.1.1. The West African Craton

The West African craton identified by Kennedy in 1964, is the part of West Africa consisting of Archaean and Proterozoic lower stable formations around 1600 - 1500 Ma and that would result from a continental collision.

The craton is partially masked by transgressive Proterozoic cover Upper Palaeozoic basin of Taoudeni, Tindouf, Bove and Volta (**Figure 1**).

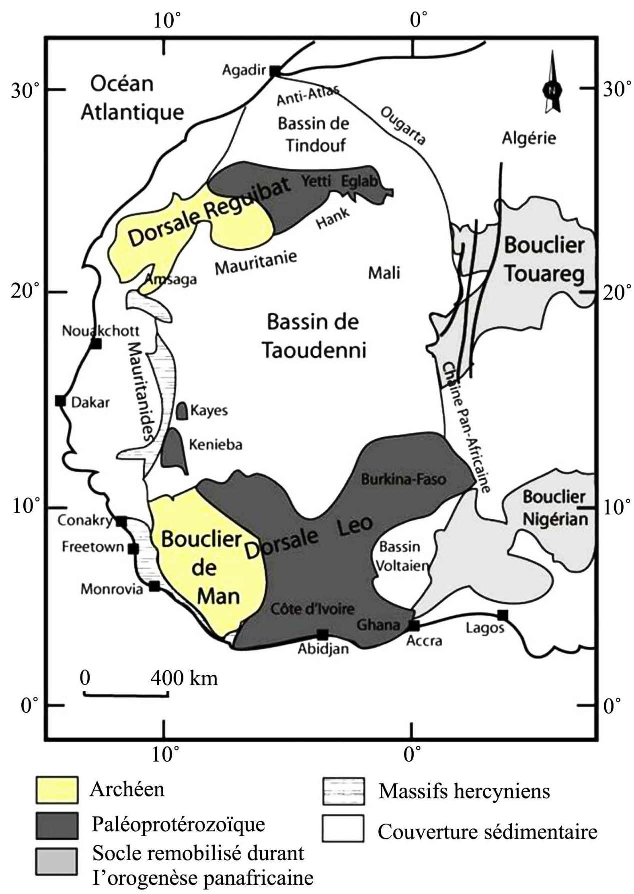

Figure 1. Main units of the West African craton.

It is bordered to the west by the poly-orogenic belts of Mauritanides and Rockelides (Pan-African and Hercynian), in the North by the domain of Anti-Atlas; in the East by the Pharusian and Dahomeian pan-African belts.

It comprises three large structural units within the North the ridge of Reguibat, in the South the dorsal of Leo or Man and in its middle part the window of Kayes and the buttonholes of Kedougou-Kéniéba.

2.1.2. Structural Setting

The study area is located in The Kedougou-Kéniéba window. The context regional shows the following characteristics:

- The Senegalo-Malian accident [8], which is in parallelto Faleme River;
- The Main Transcurrent Zone called MTZ.

In addition to these two major structures, second order structures exist. The structures N000 to N020 and N070 second order faults control the mineralization at level of their intersections; especially in the areas of change of direction of the Senegalese-Malian structure. Field observations have shown that the sequences are reversed especially where the Senegalese-Malian structure changes direction.

The Senegalo-Malian structure is interpreted as a reverse slope inclined towards the west of which the east part constituting the wall forms a vast fold (Sadiola is on a large synclinal, Loulo and Segala are on a wide anticline).

The large deposits currently known are located east of this structure and are associated with second order inverse faults [9].

3. Mineralogical Analysis

The main mineralization phase occurs late in fluid history, located in the narrow, ductile and fragile shears that deform the weathering material early of distinct form [10]. Yalea gold is bound to several sulphide phases (Pyrites and Arsenopyrites) which are the dominant phases and several phases of copper-bearing sulphides (Chalcopyrite and Tennantite); in the gangue phase, the accessory minerals are: Apatite Rutile andIlmenite and Leucite (**Table 1** and **Table 2**).

Table 1. Mineralogy of the ore.

Hydrothermal alteration minerals	Supergene alteration minerals	Minerals in the veins	Gangue	Sulfides/Mat
Albite, Ankerite, Quartz, Hematite, Sericite, Chlorite	leucoxene, covellite, chalcocite	calcite Ankerite, Quartz	Rutile, Apatite, Ilmenite, leucite	Pyrite, Arsenopyrite, jamesonite, pyrrhotite, Arsenopyrite, Galena, scheelite, tennantite, Chalcopyrite, Gold

Table 2. Mineral paragenesis.

dominant sulphides	mineral paragenesis	
	minerals	Elements
Pyrite and Arsenopyrite	Chalcopyrite + Tennantite + Scheelite + Pyrrhotite + Native Gold + Galena + Jamesonite	Fe-As-Cu-W-Au-Ag-Pb

Yalea is a deposit rich in arsenic (30% to 35% Arsenopyrite) with a combination of typical Fe-As-Cu-W-Au-Ag-Pb metal.

4. Methodology of Research

In this paper, the first work is to collect samples analysis result. The next step is to make mineralurgical tests and make a statistical data processing. The following paper presents the problematic related to the influence of Copper and Arsenic on the recovery of gold in the Yalea deposit. Multielement tests (Au, Cu, As) carried out on 37 blocks made it possible to understand that there is a correlation between these elements. But, the mineralurgical tests were carried out on 28 blocks. The last step is to make the interpretation of the elements that influence on the recovery of gold in yalea deposit.

4.1. Studies of the Elements Who Influence on the Recovery of Gold during of Mineral Treatment

Analysis of Block Models: Cu, As, Au

These models are based on core drilling data from the area (**Figure 2**).

After the survey, the cores are sampled and sent to the laboratory for phased analysis (Au, Cu, As). The results of this analysis are treated with the Vulcan/GemCom software, which allows us to have these models (**Figure 3**). These models are updated as we have data from survey (**Figure 4**).

1) Gold model block:

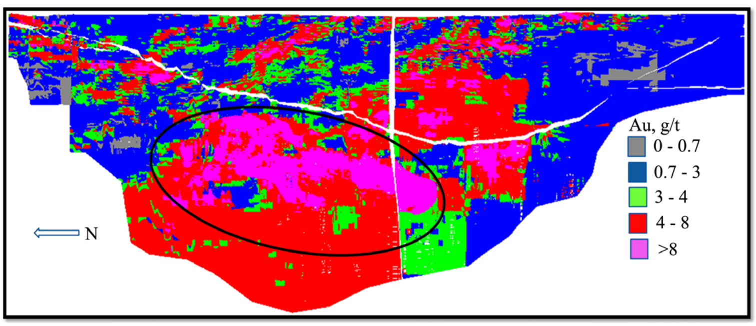

Figure 2. The gold model block.

2) Copper model block:

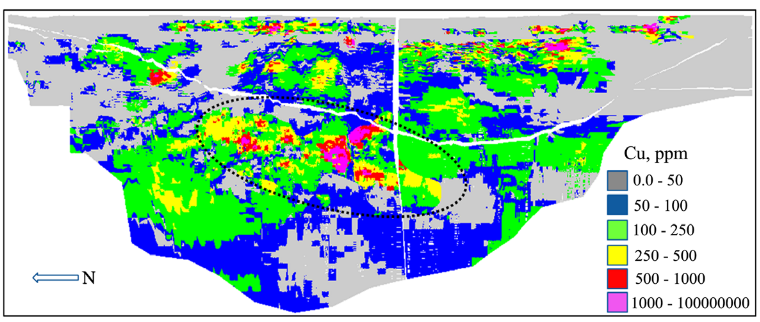

Figure 3. Copper model block.

3) Model block of Arsenic:

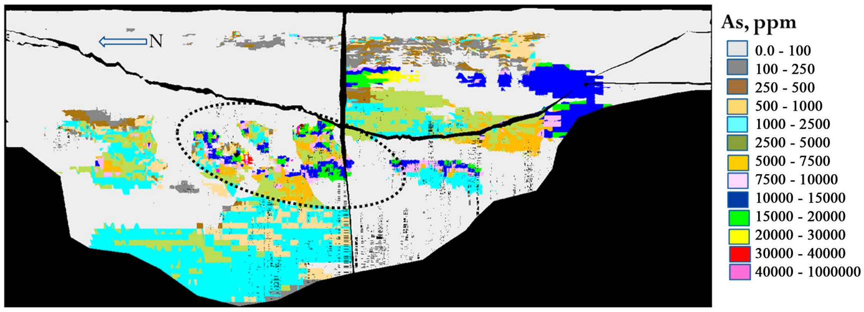

Figure 4. The model block of Arsenic.

The analysis of these three block models shows a high gold, copper and arsenic content center of the deposit. To verify the link between these three elements in the deposit, 37 blocksextracts from the deposit are sampled and sent to the laboratory for analysis multielement (Au, Cu, As) due to two (O_2) samples of 50 kg per block.

4.2. Multielement Analysis (Au, Cu, As) of Block Samples Laboratory

Statistically from the results of these 37 blocks, these two graphs show that there are a correlation between gold and arsenic on the one hand and on the other hand between gold and copper and (Or-Arsenic) vary in the same direction. But gold is more related to Arsenic (R = 0.7) than to copper (R = 0.6). This is due to the fact that Gold is in inclusion of Arsenopyrite II, but it is often found in association with chalcopyrite and/or Tennantite in fractures of pyrites II (**Figure 5**) and (**Figure 6**).

The average content of Arsenic in the blocks is higher (14,337 ppm) than the average copper (229 ppm), this is due to the fact that arsenopyrite is one of the dominant sulphides (35% of sulphides), chalcopyrite and Tennantite (5% of sulphides) are sulphides miners in the deposit. The average gold content in the blocks is 6 g/t.

These three (03) elements show almost the same signature, which confirms that Copper and Arsenic are tracer elements of Gold in the Yalea deposit (**Figure 7**).

4.3. Influence of Copper and Arsenic on Gold Recovery

It can be seen that the curve increases gradually with Log (Cu) up to 2.06. From there, it shows a plateau between 2.06 and 2.16 and beyond 2.16 it decreases (**Figure 8**).

- Log (Cu) = 2.06 is the threshold content, content beyond which the recovery no longer increases.
- The plateau between Log (Cu) = 2.06 and Log (Cu) = 2.16 shows that the recovery is stationary in this interval.

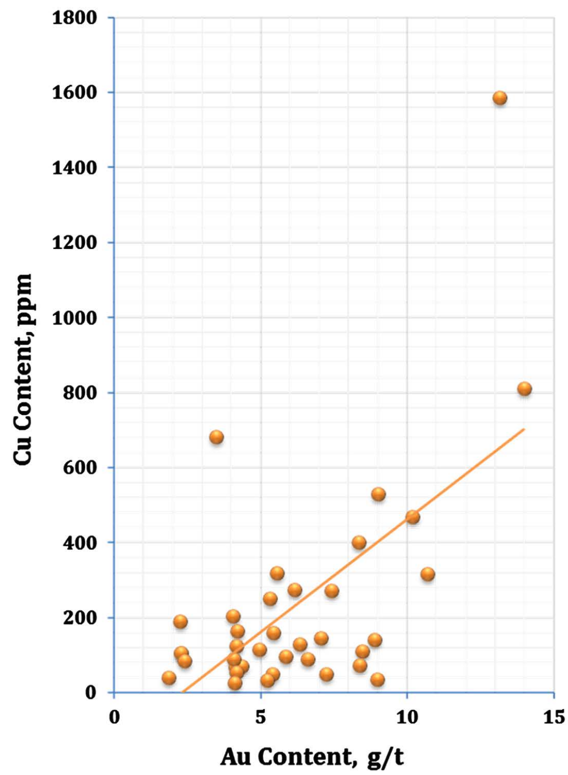

Figure 5. Relationship between Cu content and Au content in blocks.

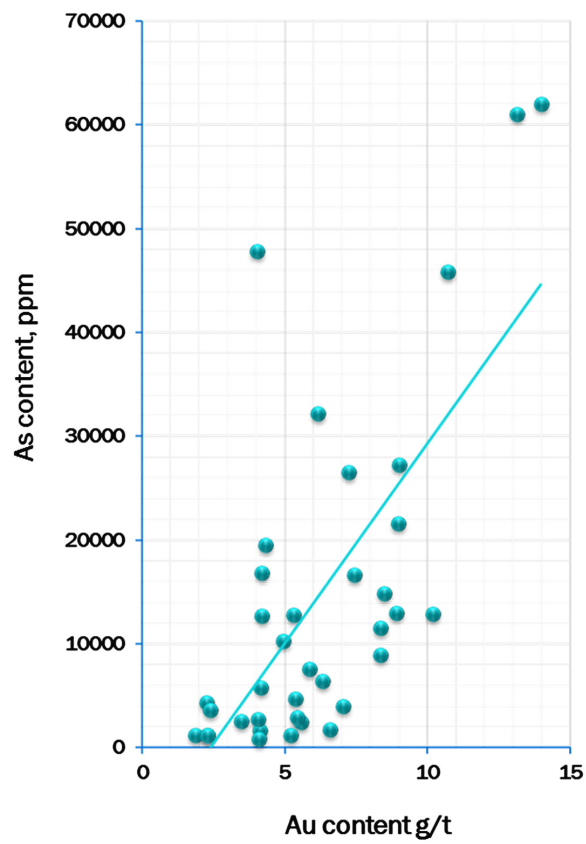

Figure 6. Relationship between As content and Au content in blocks.

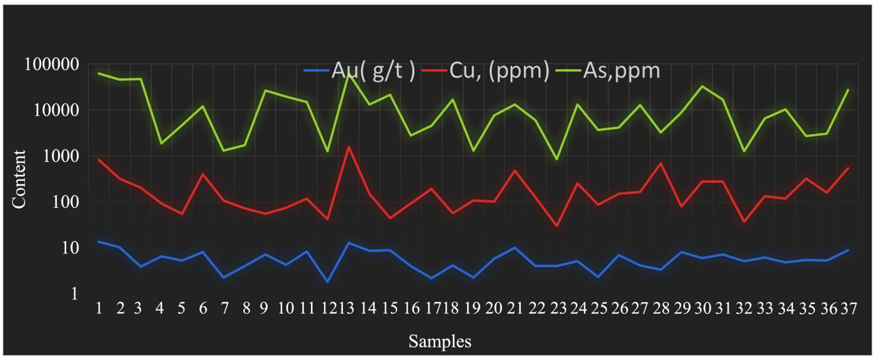

Figure 7. Curves of variation of the contents in the blocks.

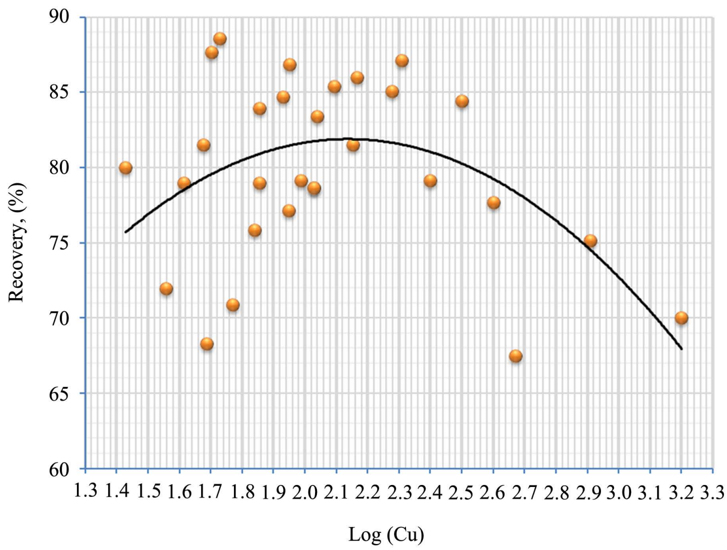

Figure 8. Recovery of gold as a function of log (Cu).

- Beyond Log (Cu) = 2.16, the recovery drops.

Log (Cu) = 2.06 and Log (Cu) = 2.16 (on the graph) lie between Log (Cu) = 2.04 and Log (Cu) = 2.17, these correspond to 110 ppm and 146 ppm of copper.

It is found that as well as copper recovery increases with Log (As) up to 3.6 which corresponds to the threshold content of Arsenic (3990 ppm) (**Figure 9**). After the curve becomes almost stationary between the Log (As) = 3.6 and Log (As) = 3.7. Beyond log (As) = 3.7 which corresponds at 4710 ppm Arsenic, recovery falls with increasing Arsenic content.

So in this interval (3990 ppm to 4710 ppm), the recovery does not vary with the content Arsenic.

The linear regression line (R = 0.5) is decreasing, which shows that the higher the content in gold increases, the more the recovery decreases. This can be explained by graphs 3 and 4 (variation of the gold content according to that of arsenic and that of copper) which shows that the gold content increases with the content of copper and that of arsenic in the blocks. We have good recoveries between 4 and 7 g/t of gold (**Figure 10**).

According to the consumption of Cyanide, we can see that, the good recoveries are between 450 to 570 g/t NaCN. The correlation coefficient is R = 0.4 (**Figure 11**).

It can be seen that the curve increases up to the point Cu = 200 ppm and H_2O_2 = 31 ppm: the copper gradually consumes Oxygen. From this point to the point Cu = 200 ppm and H_2O_2 = 39 ppm the curve becomes almost stationary, which implies that the copper has not consumed Oxygen in this interval.

This interval corresponds to the saturation interval of copper. Beyond this interval the curve increases, this shows a consumption of Oxygen by the Copper. So for a copper content of 200 ppm, it is saturated with 31 ppm of H_2O_2 (**Figure 12**).

This graph shows that there is a very high correlation (R = 0.70) between the content of Arsenic in ore and H_2O_2 consumption during pre-oxygenation.

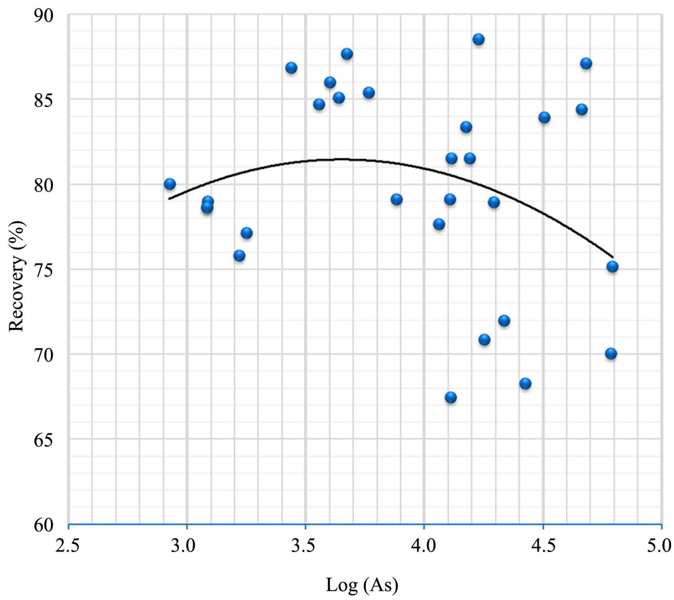

Figure 9. Gold Recovery vs. Log (As).

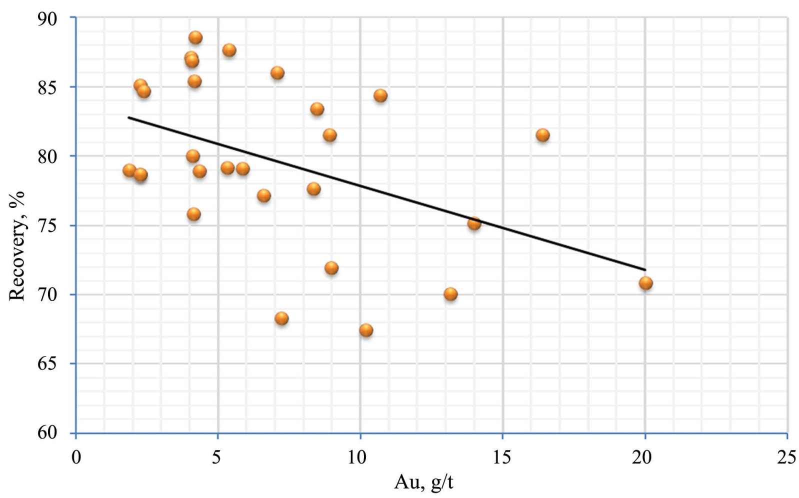

Figure 10. Gold recovery rate as a function of gold content in the ore.

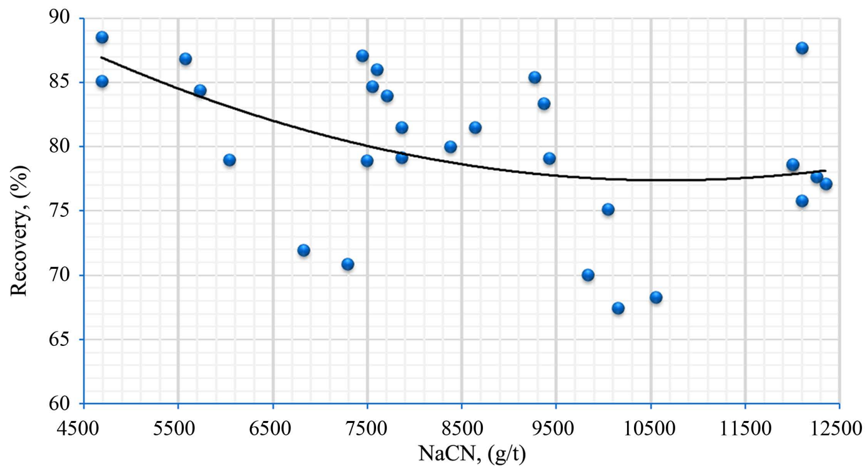

Figure 11. Recovery of gold according to the consumption of cyanide.

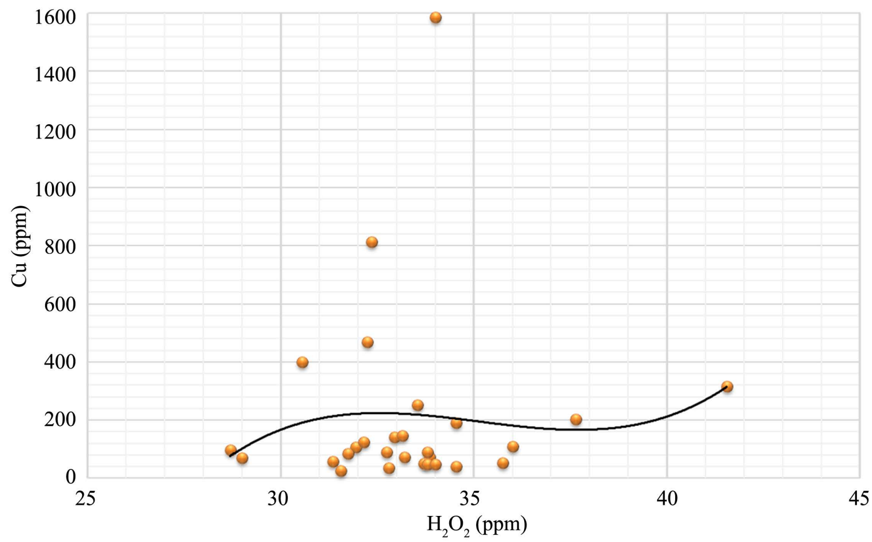

Figure 12. H_2O_2 consumption as a function of copper content.

An interpolation of the trend curve shows us a plateau at 5000 ppm of Arsenic, corresponds to the saturation range of Arsenic at 29 ppm of H_2O_2.

Beyond this content the curve rises considerably. The higher the content of Arsenic in the blocks, the more oxygen it takes mitigate it. So Arsenic is a consumer of Oxygen (**Figure 13**).

Among the elements consuming oxygen, do not forget the Iron, it oxidizes very easily. This graph shows that it consumes oxygen. It reaches saturation at 30 ppm H_2O_2 when its amount in the ore reaches 8%. Beyond 8% it starts again consumption (**Figure 14**).

5. Results and Discussion

In the Yalea deposit the higher the gold content in the blocks, the higher the content of the increased copper and arsenic, which could have a considerable impact on the gold recovery in blocks of high gold content.

In ore, the higher the gold content, the higher the copper and arsenic contents in the blocks increase, the more the recovery decreases.

The Arsenic content is higher than the copper content in the samples, but the graphs show that recovery is more related to copper grades than to arsenic. Since the correlation coefficient between copper and recovery is higher (R = 0.5) than that of arsenic with recovery (R = 0.3).

According to these figures, Arsenic is the most oxygen intensive element among these elements (As, Cu, Fe), since the correlation coefficient between its content in the blocks and the consumption of H_2O_2 is the highest (R = 0.70). After it is the Iron (R = 0.25) then the Copper (R = 0.13).

We see that the average feed content is 6 g/t with a recovery of 85% (Table 3).

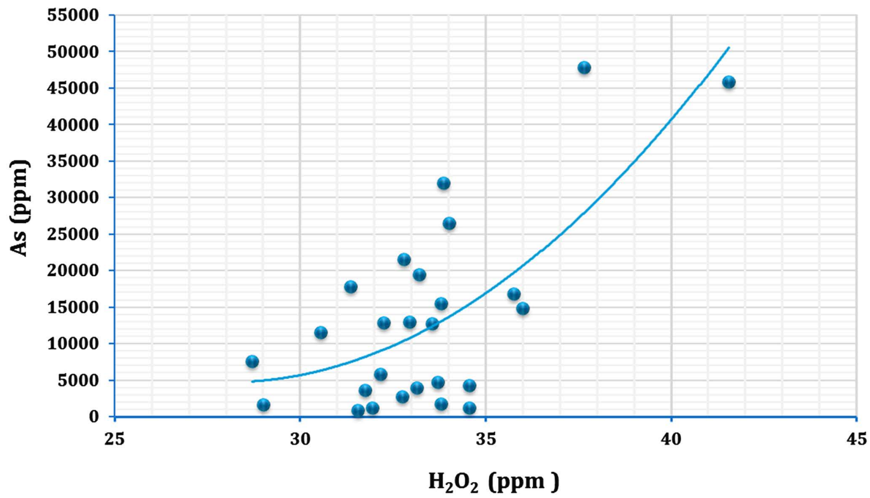

Figure 13. H_2O_2 consumption as a function of Arsenic content.

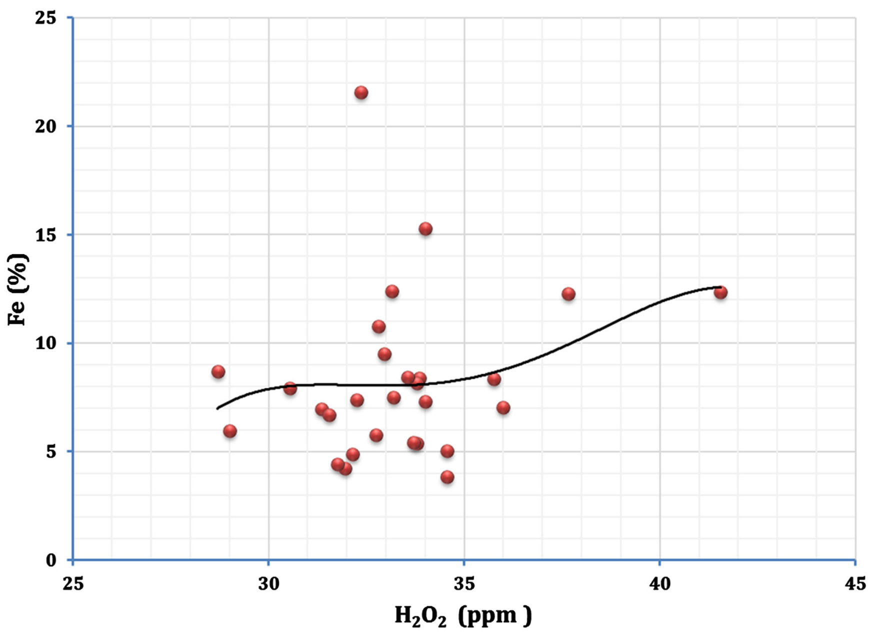

Figure 14. H_2O_2 consumption as a function of the amount of iron.

Table 3. Comparison between yalea deposit and other deposit.

Deposits	Au (g/t)	Rec (%)	NaCN (g/t)	Cu (ppm)	As (ppm)
Gara	4.8	96	620	22	10,040
Gounkoto	5.6	91	660	63	111
Yalea OPP	5.3	72	890	180	21,750
YaleaUG	8.0	80	850	594	24,587
Content average	6	84	755	215	14,122

This recovery is low due to the fact that the recovery of Yalea OPP is very critical 72% [10]. The interaction of hydrothermal fluids with metamorphosed carbonaceous matter (CM) could be one of the causes of the reduction of hydrothermal fluids and formation of the respective mineralization [11]. However Alamoutala gold deposit is part of the Yatela gold district, which is located in the Kédougou-Kénieba inlier (KKI), a window of deformed Birimian rocks (Paleoproterozoic, ca. 2200 - 2050 Ma) that outcrop in eastern Senegal and western Mali [12].

But in the Loulo-Gounkoto complex in the Kédougou-Kéniéba Inlier hosts three multi-million ounce orogenic gold deposits, situated along the Senegal-Mali Shear Zone [13]. It is the ore that consumes the most cyanide due to its mineralogical composition.

Containing secondary sulphides: covellite (CuS) and chalcocite (Cu_2S) which generate ions Cu^+ and Cu^{2+} which are very active with cyanide is the reason why it consumed more cyanide than Yalea UG ore that contains a relatively greater amount of copper high. The latter contains chalcopyrites which give Cu^{3+} ions less active than Cu^+ and Cu^{2+}. In this case, it is necessary to have a thorough pre-oxygenation and a cyanidation procedure; the one that does will not be more economical.

6. Conclusions

In this paper, Copper and Arsenic are tracer elements of Gold in the Yalea deposit, which is directly observable on block models (high concentrations of gold correspond to the high concentrations of copper and arsenic).

The interpretation of the results of the mineralogical tests carried out on the 29 blocks showed that gold recovery from Yalea ore is a function of the grade of copper and Arsenic in the ore, as well as the dosage of Cyanide.

The oxidized ore of Yalea has a considerable influence on the recovery rate of gold, due to the presence of secondary sulphides (covellite and chalcocite).

Arsenic is more related to gold ($R = 0.5$) than copper ($R = 0.2$), and its content is higher than that of copper in the blocks. But recovery is more related to grades copper ($R = 0.5$) in the ores than at the Arsenic contents ($R = 0.3$).

In conclusion, copper and Arsenic are elements that have a considerable influence on the gold recovery in the Yalea deposit.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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