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Relationship between Mineralogy and Gold Recovery in Palaeoplacer Tarkwaian Conglomerate, Ghana

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Abstract:

This paper focused on mineralogy and gold extraction from three Palaeoplacer gold pits at Tarkwa in Ghana. The rocks investigated were generally composed mainly of quartz, minor chlorite, sericite and plagioclase with traces of epidote. Ore minerals were mainly pyrite, magnetite, pyrrhotite, chalcopyrite and hematite. The percentage of gold recovered ranged from 89.64 % to 99.21 %. Lime consumption for virtually all ranged from 1.0 to 1.5 kg/t except for partially weathered rocks from Pit 3 which recorded 5.30 kg/t. Cyanide consumption was moderate and ranged from 0.01 to 0.10 kg/t. Gold recovery in the Tarkwaian ore was related to sulphide mineralogy factor involving pyrrhotite (Po) and pyrite (Py), and platy mineralogy factor comprising of chlorite (Chl) and sericite (Ser) as follows:

$$\text{Gold Recovery} = 100 - \frac{(0.70 (\text{Po}^3 + \text{Py}^2) + 0.85 (\text{Chl}^{1.5} + \text{Ser}))}{\text{Po} + \text{Py} + \text{Chl} + \text{Ser}}$$

This equation should be developed to predict recovery from known modal composition of the palaeoplacer ores.

Keywords: Mineralogy, Gold Recovery, Palaeoplacer Tarkwaian Conglomerate, Mineralogy

1. Introduction

Palaeoplacers which consist of lithified conglomerates contain small rounded pebbles of quartz in a matrix of pyrite, fine quartz, micaceous materials, and small quantities of heavy, resistant minerals such as magnetite, uraninite, platinum group metals (PGMs), titanium minerals, and gold. There are several palaeoplacer deposits which include the widely known Witwatersrand deposit in South Africa. Others include Jacobina, Blind River-Elliot Lake (Canada), and Tarkwa (Marsden and House, 2006). Geometallurgy is a cross-discipline approach that combines geological and metallurgical information to create spatially-based predictive model for mineral processing plants, production planning and management to improve resource recovery efficiency (Lamberg, 2011; Baumgartner *et al.*, 2011; and Williams and Richardson, 2004). The Tarkwaian is mined at Goldfields Ghana Limited (both at Tarkwa and Damang) and AngloGold Ashanti (Iduapriem) Limited. At the western and southern parts of Goldfields Tarkwa mine are prominent breccia reef, and a unit of basal conglomerates. The Basal or Main reef is the most persistent conglomerate bed in the Tarkwa Goldfields area and is by far the richest in gold. The pebbles in the rock is generally well sorted with a matrix which is made up of quartz, hematite with ilmenite, magnetite and rutile. Minor constituents are sericite, chlorite, tourmaline, garnet, zircon and gold. This paper examined the mineralogical composition of various Tarkwaian conglomerates at Tarkwa area at various stages of weathering as to whether they are fresh, partially oxidised or weathered. Their mineralogical composition was used to develop a formula to relate gold recovery and key minerals that affect extraction.

2. Materials and Methods

Samples were taken from three active pits namely, Pits 1, 2 and 3 at a gold mine at Tarkwa from various reefs according to their degree of weathering (weathered, partially weathered and fresh). Hence samples from Pit 1 were labeled as F1, P1 and W1 showing fresh, partially oxidised and weathered rocks respectively. The individual rock samples weighing about 2 kg were described with a hand lens followed by thin and polished section preparation at Geological Engineering laboratory at University of Mines and Technology, Tarkwa. Petrographic description was undertaken in both transmitted and reflected light using Leica DM 2700P. The modal percentage of minerals was estimated by point counting. Mineral abbreviations were after Whitney and Evans (2010). Samples were grouped according to their degree of weathering into three batches weighing about 30 kg for metallurgical studies which consisted of crushing (work index and abrasion index), cyanide bottle roll test, reagents consumption. All solid samples were well washed and dried before analysis. For Cyanide Bottle Roll Testing, samples were crushed to all passing 2 mm and further milled

to 80 % passing 106 μm . One kilogram of each sample was leached at 50 % solids and cyanide strength of 250 ppm. pH was kept at 11 by the addition of lime. Samples were taken at regular intervals to monitor leaching kinetics and titration was performed on solutions. Both solid and solutions were analysed at Goldfields Laboratory by atomic absorption spectroscopy (AAS) and fire assay respectively after having been leached for 36 hours. The final tailings and two identical head grade samples of each were also assayed.

3. Results and Discussions

3.1. Petrography

The conglomerate is greenish grey when fresh, brown to yellowish brown when weathered and dark brownish grey to dark greyish brown when partially oxidised. Fragments, generally consist of quartz pebbles with size ranging between 3 to 85 mm, sub-rounded to rounded, moderately-sorted to well-sorted, poorly packed to well-packed. The percentage of pebbles varied between 1 to 80 %. Mineralogically, the rock is composed of plagioclase feldspars and opaque minerals within the matrix.



Figure 1: Photograph of Conglomerate

The conglomerate which could be fractured contained quartz, chlorite, sericite, pyrite, chalcocopyrite, hematite, magnetite, pyrrhotite with traces of epidote (Fig 2). The green coloration in the fresh conglomerate is due to presence of chlorite. Partially weathered conglomerate is whitish grey as plagioclase breaks down to sericite and kaolin. The weathered rocks are brown due to iron oxide stains and friable as the fractures become loose. Fig 2A shows recrystallised quartz pebble in contact with foliation marked by fine chlorite. Highly corroded pyrite occurs in the matrix (Fig. 2B). Pyrite which is partially weathered forms pyrrhotite (Fig. 2C). Elsewhere pyrite was partially replaced by magnetite (Fig. 2D).

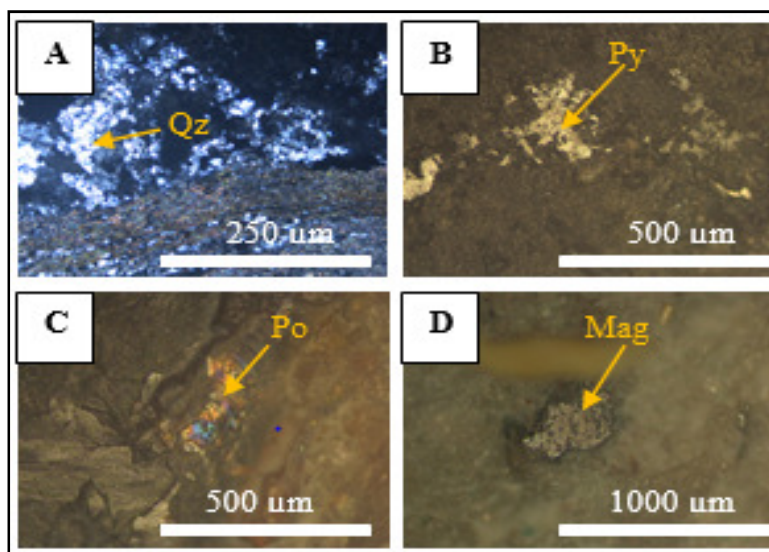


Figure 2: Photomicrograph of conglomerate in reflected light A, B & C) Plane Polarised Light D) Crossed Polarised Light

The rocks are generally composed mainly of quartz (55 - 90 %), minor chlorite (3 - 20 %), sericite (1 - 10 %), and plagioclase (2 - 10 %) with traces of epidote (2 %). Ore minerals are mainly pyrite (2.5 - 18.5 %), magnetite (0.5 - 1 %), pyrrhotite (0.5 - 2 %), chalcocopyrite (0.5 %), and hematite (0.5 %) (Tables 1.1 and 1.2).

Table 1 shows that high chlorite and iron oxides caused high reagent consumption as chlorite consumes acids while iron oxide may be a preg-borrower and lime consumer. Reactive sulphide minerals such as pyrite, pyrrhotite and partially oxidised sulphides are cyanicides and might have led to high reagents consumption.

Sample No. / Mineral	Qz	Chl	Ser	Py	Mag	Ccp
P1	75.00	12.00	5.00	6.50	1.00	0.50
W1	65.00	14.00	7.67	11.50	1.00	0.50
F2	71.50	20.00	4.50	2.75	0.50	0.50
W2	74.33	17.00	2.67	5.33	0.50	0.17
P3	71.83	14.33	4.00	6.58	0.25	0.08
F3	74.00	10.00	3.00	2.50	0.00	0.50

Table 1: Modal Composition of Minerals in the Ore Types

Mineralogy	Oxidation State of Sample					
	P1	W1	F2	W2	F3	P3
Quartz	75.0	65.0	71.5	74.3	74.0	71.8
Chlorite	12.0	14.0	20.0	17.0	10.0	14.3
Sericite	5.0	7.67	4.5	2.7	3.0	4.0
Plagioclase	0.0	0.0	0.0	0.0	10.0	1.67
Epidote	0.0	0.0	0.0	0.0	0.0	0.33
Pyrite	6.50	11.5	2.8	5.3	2.50	6.58
Pyrrhotite	0.0	0.33	0.0	0.0	0.0	0.92
Hematite	0.0	0.00	0.25	0.0	0.0	0.00
Magnetite	1.0	1.00	0.50	0.5	0.0	0.25
Chalcopyrite	0.50	0.50	0.50	0.2	0.50	0.08

Table 2: Modal Composition of Conglomerate by Oxidation States

3.2. Reagents Consumption

Natural pH of the ore was also determined and the results were tabulated in Table 3.

Sample and Oxidised State	Natural pH	Lime (kg/t)	CN (kg/t)	Actual Rec.	Calc. Rec.
P1	7.80	1.06	0.01	99.2	96.5
W1	7.94	1.42	0.10	96.7	94.5
F2	7.80	1.00	0.01	90.7	96.8
W2	6.54	1.04	0.02	96.6	96.4
F3	7.52	1.34	0.03	98.1	97.7
P3	7.07	5.30	0.03	89.6	96.4

Table 3: Reagent Consumed by the Various Ore Types

The natural pH of the various ore types ranged between pH 6.5 to 8.0. At lower pH, more lime would be required to increase the leaching pH. Also, lime consumed after the 24-hour ranged from 1.00 to 5.30 kg/t. The concentration range for non-alkali consuming ores to achieve the required leaching pH is 0.15 to 0.25 kg/t (Marsden and House, 2006). From the results obtained, all the various ore types gave high lime consumption. Oxidation processes usually leads to the conversion of pyrite to oxides such as hematite with the release of acidic components which may be responsible for the high lime consumption. The total cyanide consumed ranged from 0.01 to 0.1 kg/t. All the ore types except weathered rock from Pit 1 (W1) which was very soft, had cyanide consumption of 0.10 kg/t. The low cyanide consumption may be due to the low cyanicides such as pyrrhotite and iron oxides present in the ore. Iron oxides such as hematite (Fe_2O_3) and magnetite (Fe_3O_4) are sparingly soluble or insoluble. Iron sulphides (pyrite and pyrrhotite), may also be oxidised to the hydrated sesquioxide form goethite (FeOOH) and limonite ($\text{FeOOH}\cdot n\text{H}_2\text{O}$) which are more soluble and may also cause some cyanide consumption.

There are several factors which affect gold dissolution, these include oxygen and reagent concentration, the mineralogy of ore among others. The percentage recovery of the weathered rocks of Pit 2 and Pit 1 were 96.6 % and 97.7 % respectively. For the partially weathered rocks of Pit 3 and Pit 1, the percentage recovery was 89.6 % and 99.2 % respectively. Sulphide minerals in the ore comprise of pyrite and pyrrhotite. Fresh rocks from Pit 2 and Pit 3 had percentage recovery of 90.7 and 98.1 % respectively. In terms of lime consumption, all the samples with the exception of the partially weathered rock from Pit 3, had no significant difference and ranged from 1.00 kg/t to 1.42 kg/t. However, the partially weathered rocks from Pit 3 consumed 5.30 kg/t of lime. The high consumption of lime may be as a result of acid generated as pyrite breaks down to pyrrhotite. Cyanide consumption ranged from 0.01 to 0.10 kg/t.

An equation was deduced using factors related to the main mineralogy that affect the gold recovery i.e. pyrrhotite, pyrite, chlorite and sericite.

Let A be sulphide mineralogy factor involving pyrrhotite and pyrite. This factor is not affected by the observation by Mahlangu *et al.* (2007) that sulphides, especially, pyrrhotite react with cyanide and oxygen during leaching. Let also factor B be for on platy minerals involving chlorite and sericite as shown in equations 1 and 2.

$$A = 0.70 (Po^3 + Py^2) \quad (1)$$

$$B = 0.85 (Chl^{1.5} + Ser) \quad (2)$$

$$\text{Gold Recovery} = 100 - \frac{(A + B)}{Po + Py + Chl + Ser} \quad (3)$$

Any deviation of calculated recovery percentage from actual recovery of gold may be due to errors in point counting which according to Neilson and Brockman (1977) and Demirmen (1971) could be on fine grains which have sizes lower than distance between grid point. The tarkwaian conglomerate had sericite and chlorite and pyrrhotite, an alteration product of pyrite and its colloidal versions. The actual recovery (AR) and calculated recovery (CR) are presented in Table 3. Lower recovery in partially weathered rocks from Pit 3 may be due higher pyrrhotite content (Tables 1.2 and 1.3).

4. Conclusions

Ores at Goldfields Tarkwa mine were mainly conglomerate with various proportions of sandstone matrix. The rocks were composed mainly of quartz (55 - 90 %) minor chlorite (3 - 20 %), sericite (1 - 10 %), and plagioclase (2 - 10 %) with traces of epidote (2 %). Ore minerals are mainly pyrite (2.5 – 18.5 %), magnetite (0.5 – 1 %), pyrrhotite (0.5 – 2 %), chalcopyrite (0.5 %), and hematite (0.5 %). Rock strength in terms of work indices ranged from 10.80 to 15.09 kWh/t whiles abrasion indices ranged from 0.34 to 5.15. Gold recovery and chemical consumption were generally good. The percentage of gold recovered ranged from 89.6 % to 99.2 %. At lime consumption for samples ranging from 1.0 to 1.5 kg/t except for partially weathered rocks from Pit 3 with a higher value of 5.30 kg/t, cyanide consumption ranged from 0.01 to 0.10 kg/t. Gold recovery in the Tarkwaian was related to sulphide mineralogy factor involving pyrrhotite (Po) and pyrite (Py) and platy mineralogy factor involving chlorite (Chl) and sericite (Ser) as follows:

$$\text{Gold Recovery} = 100 - \frac{(0.70 (Po^3 + Py^2) + 0.85 (Chl^{1.5} + Ser))}{Po + Py + Chl + Ser}$$

This equation should be developed to predict recovery from modal composition of the palaeoplacer ore in gold treatment plants.

5. References

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