

# CHLORIDE AS AN ALTERNATIVE TO CYANIDE FOR THE EXTRACTION OF GOLD - GOING FULL CIRCLE?

C. J. FERRON AND C. A. FLEMING — SGS; D. DREISINGER — UNIVERSITY OF COLUMBIA; AND T. O'KANE — O'KANE CONSULTANTS INC.

## ABSTRACT

At the present time, cyanide is the most widely used reagent to extract gold from its ores and concentrates. However, its use in mining has become the focus of intense attack by various groups throughout the world; as a consequence, a renewed effort has been launched to find suitable alternative lixiviants to recover gold.

Chlorination was the most popular process to extract gold, before it was rendered obsolete with the advent of the cyanidation process at the turn of the last century, not least because it required the use of potentially hazardous and costly chlorine to oxidize/complex the gold.

The PLATSOL<sup>®</sup> process, originally designed to recover the platinum group metals (PGM's) from their ores and concentrates, provides an alternative to cyanide for gold ores. The process generates oxidizing conditions in the autoclave capable of forming the Au<sup>3+</sup> ion, and gold chloro-complexes result from the addition of small quantities (~5-10 g/L) of sodium chloride to the autoclave.

The principles of the PLATSOL<sup>®</sup> process are briefly described, and several applications of the process to gold concentrates are presented. Various options available to recover gold from PLATSOL<sup>®</sup> leach solutions are also discussed.

## INTRODUCTION

For many decades, cyanidation has been the process of choice for the extraction of gold from its ores and concentrates. In recent years, however, its commercial application has been challenged due to perceived environmental concerns, and the use of cyanide has even been banned in some parts of the world.

When cyanidation was developed by MacArthur and the Forrest brothers at the end of the 19th century, one of the main processes it displaced was chlorination. Several chlorination routes were practiced at that time [1]. Some made use of chlorine gas (Deetken or Mears processes), another added bleaching powder and sulphuric acid (Munktell process), still another blended potassium permanganate, salt, and sulphuric acid (Black-Etard process). Chlorine/hydrochloric acid mixtures are still used today to dissolve gold and platinum group metals (PGM's) in various

precious metals refineries around the world.

Chloride processes for gold extraction have continued to attract some attention [2,3], although limited. Volatilization of gold chloride has been studied [4,5,6], and gold has been commercially recovered from an antimony-rich slag by chloride hydrometallurgy in South Africa [7]. Other investigators suggested high temperature (170-200°C) acid pressure oxidation in concentrated chloride (>5 N Cl) solutions [8,9].

This paper discusses the development of the PLATSOL<sup>®</sup> process, which has been shown to dissolve gold and PGM's very effectively under high temperature pressure oxidation conditions, using dilute chloride solutions. Examples of applications of the PLATSOL<sup>®</sup> process to various gold concentrates are presented. Application of the process to preg-robbing gold ores, and to silver ores, is also briefly discussed. Methods of

recovering the gold from the PLATSOL<sup>®</sup> liquors are examined.

## DEVELOPMENT OF THE PLATSOL<sup>®</sup> PROCESS

### Fundamentals

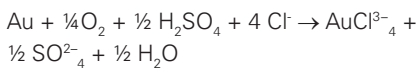
Pressure oxidation has been used commercially since 1985 to pretreat refractory gold ores prior to cyanidation [10]. The objective of the pressure oxidation stage is to destroy the sulphides in the ore/concentrate and liberate the gold, making it accessible during the subsequent cyanidation stage. During pre-oxidation, gold remains chemically inert.

Under specific conditions, however, indications are that gold could be solubilized during the pre-treatment stage. Information released by Barrick in the early 1990's revealed that at times up to 40% of the gold in their Goldstrike ore was solubilized in the autoclave and reprecipitated later. Goldstrike ores contain some soluble chlorides. The Con Mine in Canada has operated with about 700 mg/L Cl<sup>-</sup> in the autoclave feed slurry, and has experienced gold plating on the discharge choke nozzle [11], supporting the concept of gold being solubilized and reprecipitated during flashing. Bench and pilot plant tests on Twin Creeks Mine ore by Santa Fe Pacific Gold Corporation confirmed that gold could be solubilized by chloride under certain autoclave operating conditions, and it was then reprecipitated on organic carbon [12].

The PLATSOL<sup>®</sup> process has been described in several papers [13,14], and can be simply described as a high temperature (≥200°C) pressure oxidation process, designed to dissolve base metals (Cu, Co, Ni) and precious metals (Au, Pt, Pd,...) in a sulphate environment containing low concentrations of chloride ion.

The novelty of the PLATSOL<sup>®</sup> process is that it makes use of a phenomenon considered by others as a serious problem, by defining precisely the requirements to dissolve gold (and the PGM's) in the autoclave using low concentrations of chloride, and to keep these metals in solution until they can be recovered from the autoclave discharge liquor.

The solubilization of metallic gold under acidic, oxidizing conditions in the presence of chloride ion, can be written as [11]:



The area of stability of the gold in chloride medium is illustrated in Figure 1 [15].

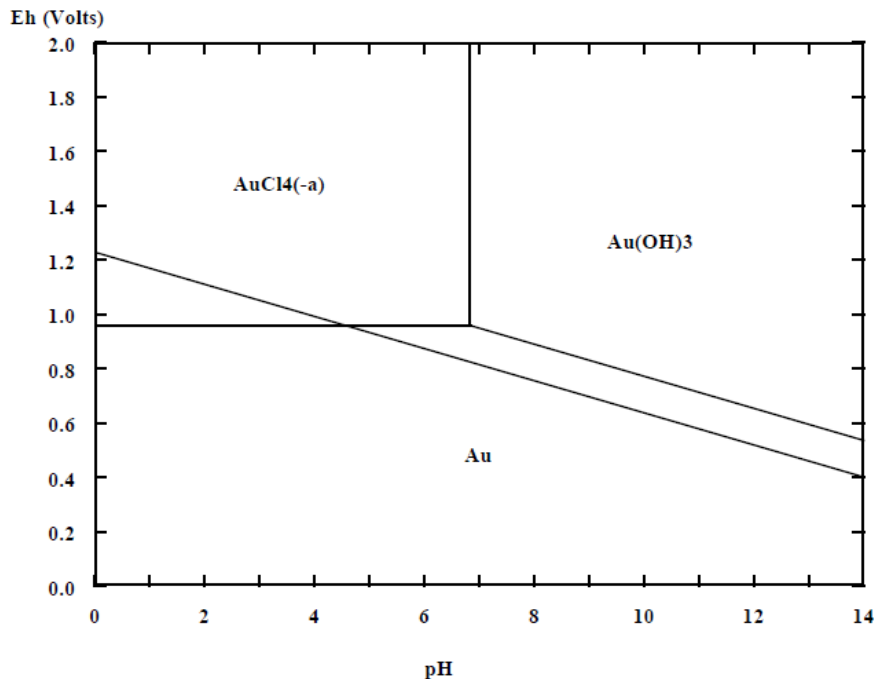


Figure 1: Eh - pH diagram for the Au-Cl-H<sub>2</sub>O system at 25°C. [Au] = 0.00001M; [Cl] = 0.2M

Although the diagram indicates that from a thermodynamics point of view oxygen should be a strong enough oxidant below pH 4 to oxidize gold and form the chloro-complex in the presence of chloride, the reality is, as indicated by the earlier chlorination processes, that a much stronger oxidant (chlorine, permanganate, hypochlorite) has to be used to obtain practical rates of reaction.

Figures 2 and 3 present the results of bench scale PLATSOL<sup>®</sup> tests conducted on concentrate from the NorthMet project in Minnesota, which assayed 13.8% Cu, 3.52% Ni, 2.2 g/t Au, 1.8 g/t Pt and 8.9 g/t Pd.

The results confirm the suitability of the PLATSOL<sup>®</sup> process to not only solubilize the gold, but also to keep it in solution after cooling the autoclave discharge. More particularly, these results showed that as little as 0.1 M chloride was sufficient, to achieve high extractions of gold, platinum and palladium from that concentrate under the PLATSOL<sup>®</sup> conditions.

Temperature also plays a critical role, more so for platinum and palladium than for gold, within the range tested.

Regarding the oxidation of gold, it has been proposed that the Fe<sup>3+</sup>/Fe<sup>2+</sup>

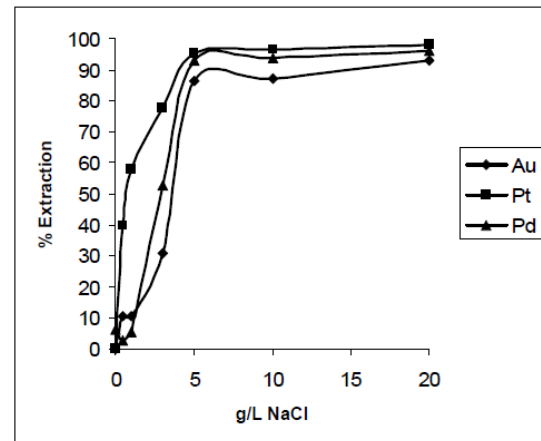


Figure 2: Effect of chloride additions on metal extractions (225°C, 2 hours)

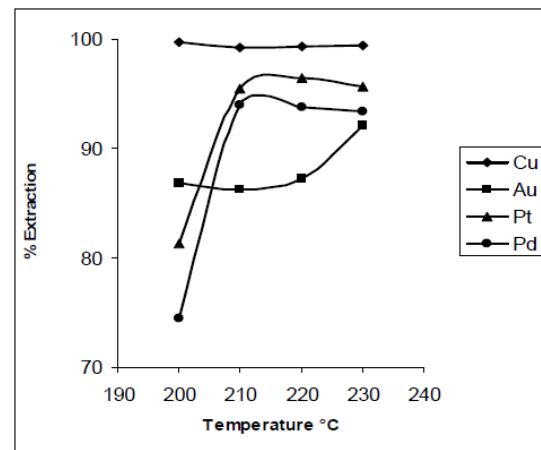


Figure 3: Effect of temperature on metal dissolutions (5 g/L NaCl, 2 hours)

couple is the actual oxidant under the temperature conditions of the PLATSOL® process [11,16].

The PLATSOL® process was initially developed and piloted for the treatment of NorthMet Cu/Ni/PM concentrate, and it was later successfully applied to numerous other concentrates of that type.

Tables 1 and 2 present the composition of various concentrates and the results of standard PLATSOL® batch tests conducted on the same concentrates.

Although the type of concentrates tested varied widely, gold extractions during sighter PLATSOL® tests were usually good, notwithstanding that some of the undissolved gold could have been encapsulated in gangue.

#### TREATMENT OF COPPER GOLD SULPHIDE CONCENTRATES

Gold contained in copper sulphide concentrates represents a significant source of gold. During conventional pyrometallurgical treatment of these concentrates, gold follows copper metal and is eventually concentrated in the refinery anodic slimes, from which it is well recovered.

Several hydrometallurgical processes have been proposed in recent years to treat copper concentrates; in all these processes, gold can be recovered from the leach residue, generally using cyanidation techniques; depending on the copper leaching conditions, cyanide consumption can be prohibitively high unless soluble copper ions are very efficiently washed from the solids and other cyanide consuming species (such as elemental sulphur) are efficiently separated from the solids prior to cyanidation. The notable exception is the Intec process, where gold is dissolved together with copper.

Based on the success of the PLATSOL® process to solubilize gold from Cu-Ni-PGM's concentrates, it seemed natural to extend the applicability of the process to copper-gold concentrates. Since chalcopyrite is the most abundant, but most refractory, of the copper sulphide minerals, the PLATSOL® process was

Table 1 Analyses of various Cu-Ni concentrates tested

ELEMENTS %	CONCENTRATE TYPE								
	A	B	C	D	E	F	G	H	I
Cu	4.4	2.6	3.2	5.8	2.1	12	4.2	2.4	5.5
Ni	9.9	4.7	5.7	4.1	3.1	3.01	7.7	0.9	10.3
Fe		19.0	23.8	17.1	12.6	33.9	35.9	19.2	
S		33.7	14.1	16.3	7.3	24.5	34.1		25.3
Au, g/t	2.5	3.6	4.0	12.4	5.0	0.9	0.5	3.0	2.1
Pt, g/t	6.0	24.6	81.1	12.3	490	0.9	1.4	5.3	11.0
Pd, g/t	14.4	38.9	59.8	143	294	2.8	2.0	10.1	7.5

Table 2 Performance of the PLATSOL® process on various Cu-Ni concentrates - scoping tests (10-20 g/l NaCl; 220°C; 50 g/l H<sub>2</sub>SO<sub>4</sub> initial; 100 psi O<sub>2</sub> overpressure)

% RECOVERY	CONCENTRATE TYPE								
	A	B	C	D	E	F	G	H	I
Cu	99.9	98	99.9	99.9	99.9	99.3	99	99.3	99.7
Ni	99.9	99	99.9	99	99	93.8	99.6	98.7	98.9
Au	93	83	96	99	83	97.1	84.3	96	97.5
Pt	72	80	76	95	51	97.4	98.2	99	97.7
Pd	97	93	94	94	80	98.1	93.9	98.4	96.2

Table 3 Characterization of Chalcopyrite concentrates tested, with PLATSOL® conditions and results

ORIGIN	CHILE	CANADA	AUSTRALIA
Assays			
% Cu	28.9	32	26.1
% S <sup>2-</sup>	29.6	28.5	29.3
g/t Au	5.8	2.5	12
PLATSOL® Conditions			
T (°C)	225	225	225
g/L NaCl	10	10	10
P <sub>80</sub> (µm)	15	20	15
Duration (hrs)	2	2	2
PLATSOL® Results			
% Cu extracted	99.7	99.8	99.9
% Au extracted	95.9	93.1	88.3

tested on a few gold-containing chalcopyrite concentrates.

Table III presents the chemical analyses of three chalcopyrite concentrates tested recently, together with test parameters and results.

Most of the copper (>99.7%) and a significant proportion of the gold were dissolved, using unoptimized conditions, without having to re-leach the autoclave residue and, more importantly, without having to use cyanide.

#### APPLICATION OF THE PLATSOL® PROCESS TO REFRACTORY GOLD CONCENTRATES

Based on the results presented earlier, the next logical step was to examine the applicability of the PLATSOL® process for refractory gold concentrates. The definition of refractory concentrates deserves some attention, since that word covers quite a wide range of situations. A gold concentrate could be defined as refractory if it

does not respond economically to the standard cyanidation process, either because gold extraction is too low or because cyanide consumption is prohibitively high. Low gold extractions by cyanidation could be caused by very fine dissemination and encapsulation of gold in the gangue, by gold encapsulation in sulphides, arsenides, sulphoarsenides, or by the presence of preg-robbars in the concentrate. It is clear that no hydrometallurgical process, including the PLATSOL® process, can recover gold encapsulated in gangue, unless an extremely fine grind is applied.

Similarly, from the background information presented earlier, it is apparent that the gold chloro- complex is preg-robbled during autoclaving in the presence of pre-robbing ore constituents, and therefore the PLATSOL® process cannot be used successfully with preg-robbing ores or concentrates. Table IV below presents the chemical analysis of a few refractory gold concentrates (non preg-robbars) on which the PLATSOL® process has been tested, as well as the results of scoping tests. For all 3 concentrates, direct cyanidation extracted less than 20% of the gold.

The results indicated that non preg-robbing refractory gold concentrates can be treated using the PLATSOL® process. Gold extractions of 90% or higher were achieved with 4 concentrates of widely different types. The results achieved on the South African sample deserve additional comment. Although the gold in the feed material was encapsulated within hematite, PLATSOL® conditions could be adjusted to open that lattice long enough to allow the gold to be accessible to the liquid phase, thence to be solubilized.

Work is continuing to reduce the retention time for treating this type of feed.

Table 4 Chemical analyses of 3 refractory gold concentrates, with PLATSOL® results

CONCENTRATE ORIGIN	SOUTH AFRICA	SOUTH AMERICA	GREECE	RUMENIA
Type	Au encapsulated in Fe <sub>2</sub> O <sub>3</sub>	Au encapsulated in pyrite	Au encapsulated in arsenopyrite	Au encapsulated in arsenopyrite
Chemical Analysis				
g/t Au	17.7	50.9	19.9	11.2
g/t Ag	6.8	350	19.4	146
PLATSOL® Conditions				
Temperature (°C)	225	225	225	225
Duration (hrs)	6	4	3	3
g/L NaCl	10	20	20	20
P <sub>80</sub> (µm)	25	16	15	16
PLATSOL® Results				
Au extraction (%)	90	96	96	92
Ag extraction (%)	41	5	99.5	7

#### RECOVERY OF GOLD FROM THE PLATSOL® LEACH LIQUOR

Several methods of recovering gold from PLATSOL® solutions have been tested, including activated carbon, NaSH precipitation and ion exchange. Reductants such as SO<sub>2</sub> or borohydrate, would also precipitate gold from solution.

##### Activated carbon

Activated charcoal was used as a means of recovering gold from chloride solution in the 1880's, particularly from the Australian chlorination plants [10]. Gold was loaded on the carbon up to 60% by weight, to avoid having to strip the carbon, since that process proved difficult. As a consequence, some gold was flaking off the loaded carbon. During the development of the PLATSOL® process for the NorthMet project, activated carbon was tested as a means to recover gold from leach liquors, since the possibility of using carbon-in-pulp (CIP) to directly treat hot, acidic autoclave discharge slurry would result in significant capital cost savings. Some information on the use of carbon for the gold chloro-complex was available in the literature [17,18,19].

Batch Tests on Clear Solutions Initial carbon loading tests were conducted using a clear leach solution without pH adjustment. Typical solution assayed ~17 g/L Cu, 11 g/L Ni, 0.4 g/L Fe, 0.2 mg/L Au, 0.2 mg/L Pt, 1 mg/L Pd and 85 g/L H<sub>2</sub>SO<sub>4</sub>.

The carbon used for the program was pre-attritioned Calgon GRC 4/16. Results are presented in Table 5.

These initial results showed that gold and the PGM's could be loaded onto activated carbon. The solution and carbon assays indicated that a counter current adsorption train should produce low barren and reasonably high carbon loadings. Some co-adsorption of base metals also occurred.

Table 5 Adsorption of metals from autoclave pregnant leach solution on activated carbon

CONDITIONS			SOLUTION ASSAYS (mg/L)				CARBON ASSAYS (g/t, %)					
Temp °C	Time h	Carbon g/L	Stream	Au	Pt	Pd	Au	Pt	Pd	Cu	Ni	Fe
20	24	5	Preg Barren	0.21	0.19	1.08						
				<0.01	0.03	0.07	14	31	197	0.72	0.54	0.18

Table 6 Elution of activated Carbon-Zadra method

PRODUCT	CARBON ANALYSES (g/t, %)				
	Au	Pt	Pd	Cu	Fe
Loaded carbon	16	118	732	0.15	0.2
Eluted carbon	0.6	1.8	7	0.002	0.2
Elution efficiency %	96	98	99	99	~0

A larger batch of carbon was loaded from a synthetic autoclave leach solution, to produce loaded carbon for elution testwork. This carbon was eluted with 10 bed volumes of hot (140°C) NaOH (5 g/L)/ NaCN (1 g/L) solution at 2 bed volumes/hour. The results of the elution test are presented in Table VI, and show that the conventional pressure Zadra technique will be effective for carbon elution in this process. Results also showed that copper was well eluted, but not iron.

Batch CIP Tests Initial results on clear liquors from the NorthMet project having confirmed that the gold and PGM chloro-complexes could be adsorbed on activated carbon from PLATSOL® liquors without prior neutralization, additional tests were conducted on PLATSOL® pulps, since the CIP process would offer the greatest potential advantage of the activated carbon process.

The extraction isotherms for gold and palladium extraction from PLATSOL® pulps from the NorthMet project are presented in Figure 4.

Results indicated that low gold (0.02 mg/L Au) and Pd barrens (0.01 mg/L) could be achieved by CIP. Loadings of 795 g/t (Au + Pt + Pd) were produced. Co-extraction of Cu + Fe + Ni was again noticed.

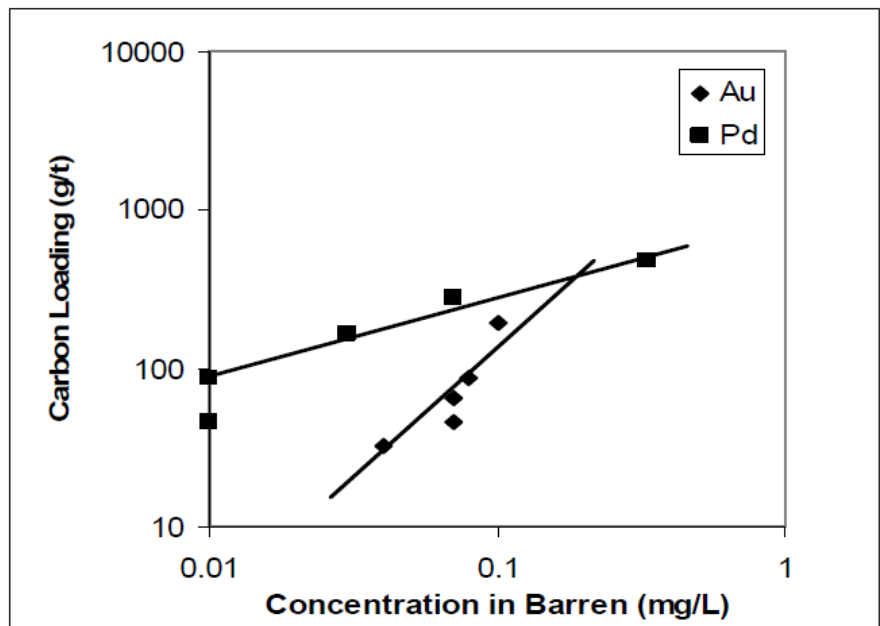


Figure 4 Extraction isotherms at 45°C for Au, Pd from PLATSOL® NorthMet pulp on activated carbon

Kinetics of loading in the CIP process were also measured for NorthMet PLATSOL® pulp.

Results are presented in Figure 5 for gold at 40 and 85°C.

Gold adsorption rates were very fast at both temperatures.

Continuous CIP/CIC Tests During the pilot plant demonstration of the PLATSOL® process for the NorthMet project, adsorption on carbon was extensively tested, first in a 6-stage (one hour per stage) CIP circuit, and then in a 6-stage CIC circuit.

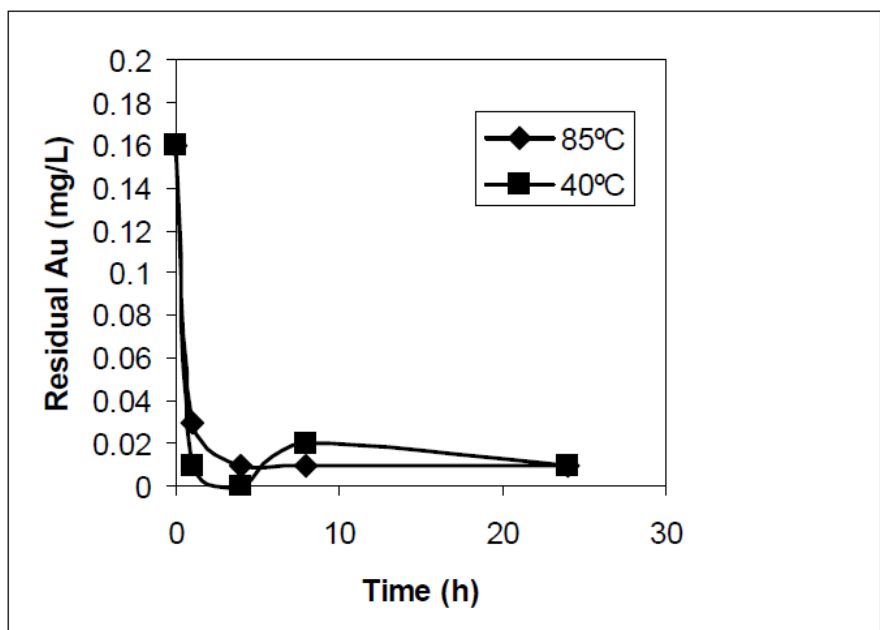


Figure 5: Kinetics of gold CIP adsorption from NorthMet PLATSOL® pulp

In each case, the loaded carbon was eluted using the Zadra process (140°C, 2 g/L NaCN, 10 g/L NaOH, 2 bed volumes/hour) and then regenerated in a tube furnace at 600°C for 30 minutes before being returned to the circuit.

Results of the CIC circuit are presented here with some details.

Table 5 presents the gold results of composite sampling over a period of 5 days (each data point representing 8 hours).

Table 7 CIC feed and discharge Au concentrations

	FEED	CIC-6 DISCHARGE
PP5-1	0.1	0.01
PP5-2	0.12	0.02
PP5-3	0.08	<0.01
PP5-4	0.09	0.01
PP5-5	0.12	0.01
PP5-6	0.14	<0.01
PP5-7	0.11	<0.01
PP5-8	0.08	0.01
PP5-9	0.12	<0.01
PP5-10	0.14	0.01
PP5-11	0.1	<0.01
PP5-12	0.13	<0.01
PP5-13	0.11	<0.01
Average	0.11	<0.01

Overall gold extraction was greater than 90%. Results indicated that gold adsorption was rapid and was essentially complete in only 3 stages. Loaded carbon for the same period assayed on average 48 g/t Au, 120 g/t Pt and 472 g/t Pd.

Average elution results for the same period are presented in Table 8.

Results showed that Zadra elution worked well for Au, Pt, Pd, Cu, Ni, but not for Fe.

Recycling of the Zadra - regenerated carbon during the pilot plant indicated a loss of activity of that carbon and, therefore, only fresh carbon was recycled during the pilot plant, while

Table 8 Concentrations of metals after elution of loaded carbons

METAL	LOADED CARBON g/t	ELUTED CARBON g/t	ELUTION EFFICIENCY %
Au	88	2.7	97.2
Pt	107	5.3	95.2
Pd	454	18.3	96
Cu	2230	25	99.4
Ni	960	70	91.6
Fe	4200	4400	8

Table 9 NaSh batch treatment of Northmet PLATSOL® pilot plant pls

CONDITIONS	% EFFICIENCY			PGM CONCENTRATE	
	Au	Pt	Pd	Cu	g/t (Au+Pt+Pd)
A	100	100	100	46.7	738
B	100	65	100	3.4	6220

attempts were made in the laboratory to improve the regeneration of the loaded carbon. Simple mineral acid (HCl, H<sub>2</sub>SO<sub>4</sub>) washing of the eluted carbon was not successful in removing the iron from the carbon.

More work is required to develop an effective elution/regeneration process that would allow the recycling of the carbon.

It is likely that the composition of NorthMet leach liquor was responsible for the poisoning of the carbon with base metals, in particular iron, and it is possible that the problems encountered with that type of solution would be less severe, or may disappear completely, with cleaner gold chloride solutions. Recently, researchers at Curtin University in Australia have announced the development of a different type of activated carbon, more suitable for chloride solutions. Certainly, the use of activated carbon for recovering gold from PLATSOL® liquors looks promising, but further study is needed to develop a robust process.

#### NaSH Precipitation

NaSH precipitation of gold and the PGM's from acidic PLATSOL® leach liquors (without pre-neutralization) is another alternative. Laboratory tests on NorthMet PLATSOL® leach liquors confirmed that, without seed recycle, one hour was sufficient to precipitate all

the gold, platinum and palladium from the acidic leach liquors. Results of bench scale NaSH treatment of NorthMet PLATSOL® leach liquors are presented in Table 9.

With low NaSH addition (Condition B, 0.25 g/L NaSH), the precipitate grade was high (~6200 g/t Au + Pt + Pd) and the copper grade low (3.4% Cu), but some of the Pt did not precipitate. With higher NaSH addition (Condition A, 0.5 g/L NaSH), all the PGM's precipitated, but quite a lot of copper also precipitated (46.7% Cu) and, therefore, the overall precipitate was low grade (~700 g/t Au + Pt + Pd). Clearly, the optimum conditions lie between A and B.

Continuous pilot plant results indicated that, in 20 minutes retention time, all of the gold and palladium was precipitated, but only half of the platinum.

It is certain that gold is easily precipitated from acidic PLATSOL® leach liquors with NaSH, but, in the case of leach liquors containing copper, minimization of the co-precipitation of copper is important. To be on the safe side, it will be preferable to co-precipitate some copper but make sure the Au + PGM's precipitation is complete. If required, the Cu-Au-PGM concentrate could be re-processed in a (very) small plant to dissolve the copper (and recycle it), and upgrade the precipitate for sale to a Au - PGM refiner.

**Ion Exchange**

As an alternative to carbon adsorption, ion exchange was also briefly tested, as a method to recover gold and the PGM's from NorthMet PLATSOL® liquor prior to neutralization. Two ion exchange resins were studied at the laboratory scale: Purolite A500 and Cognis AuRiX® 100. Some results are presented here for the AuRiX® 100 resin. Results for the Purolite A500 were similar. AuRiX100 is a weak base ion exchange resin developed by Cognis for the recovery of gold from typical cyanide leach liquors [20]. It is a typical styrene - divinylbenzene resin bead functionalized with a guanidine functional group.

The resin was tested as RIP on fresh pulps from the NorthMet PLATSOL® pilot plant trial. The extraction isotherms at 45°C are presented for gold and palladium in Figure 6.

Low gold barren was produced (0.01 mg/L) at reasonable loading (>100 g/t), and a maximum loading of 1370 g/t (Au + Pt + Pd) was measured. Results were quite promising, but further work is required to examine the elution and regeneration stages of a potential RIP process.

**RECOVERY OF SILVER USING THE PLATSOL® PROCESS**

During the PLATSOL® process, precious metals chloro-complexes are formed. Due to the low solubility of the silver chloride complex under PLATSOL® conditions (low activity of Cl ion), it is not expected to recover the silver together with the gold and the PGM's.

However, silver chloride solubility in the PLATSOL® liquors although low is finite (a few mg/L), and therefore, depending on the pulp density and the amount of silver present in the feed concentrate, silver recovery could be quite substantial in some cases, as illustrated earlier in Table IV.

This fact cannot be neglected, for two main reasons. The first one is that the limited solubility of silver chloride under PLATSOL® conditions can generate significant revenues for a project at no incremental cost. To cite an example, during the application of the PLATSOL®

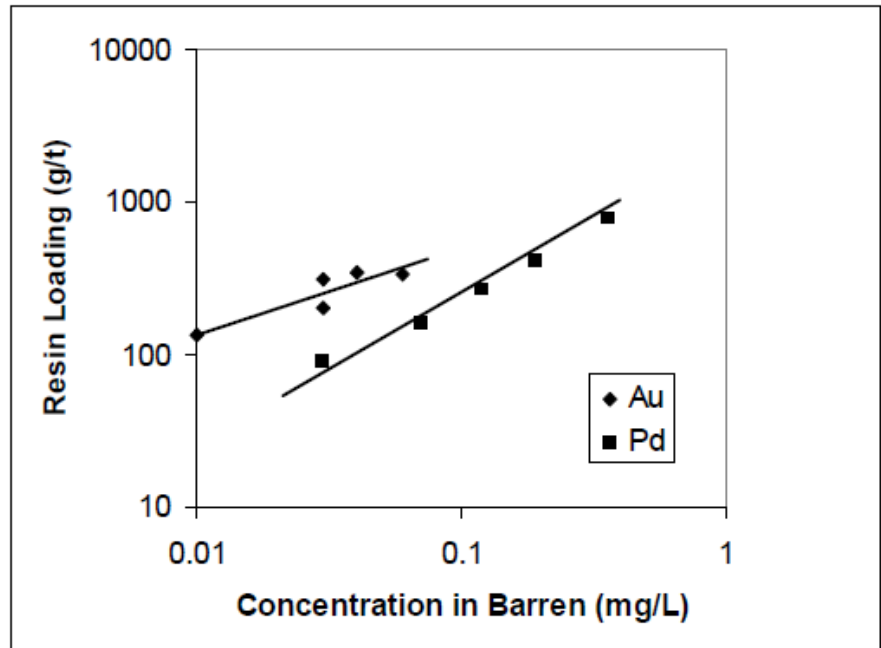


Figure 6: Extraction isotherms at 45°C for Au, Pd from PLATSOL® NorthMet pulps. AuRiX® 100 resin

process to the NorthMet concentrate, silver concentrations of up to 3000 g/t Ag were analyzed on the carbon during the pilot plant operation.

The second reason is that the presence of substantial amounts of silver in solution, together with the gold, could impact on the type of process selected to recover the gold. For example, looking back at the concentrate from Greece (Table IV), from which as much silver leached as gold under PLATSOL® conditions, loaded carbon will include as much silver as gold, and maximum gold loading of the carbon could be affected.

The case of high-grade silver concentrates is obviously different, and low extractions are expected using the PLATSOL® process. As an example, a silver-rich tetrahedrite concentrate from the USA was submitted to a standard PLATSOL® test; the concentrate assayed 16% Cu, 30% Pb, 9.8% Sb, 9.9% Fe and 3.5% Ag. After a PLATSOL® test, 99.6% of the copper was extracted, for only 0.1% of the Sb and 0.1% of the Ag. Mineralogical examination was conducted on the concentrate and the PLATSOL® residue; typical microphotographs are presented in Figure 7.

Analyses indicated that 98.9% of the silver in the concentrate was present

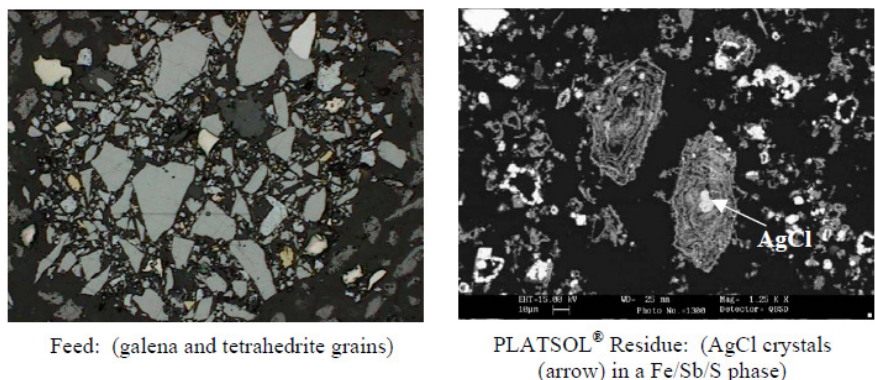


Figure 7: Microphotographs of feed and PLATSOL® residue

as tetrahedrite/freibergite  $(\text{Cu,Ag,Fe})_{12}(\text{Sb,As})_4\text{S}_{13}$ , with the remaining silver present in the galena.

After PLATSOL<sup>®</sup>, practically all the silver had been transformed to AgCl crystals. Significantly, no silver jarosite was detected. The photomicrograph of the PLATSOL<sup>®</sup> residue shows the relict tetrahedrite/freibergite grain, transformed into an iron sulphate antimonate, all the copper having been extracted and the silver re-precipitated as AgCl.

This finding opens the door to various silver recovery schemes. One option would be to process the PLATSOL<sup>®</sup> residue, now completely freed of copper, in a plant and location where cyanide use is allowed. When treated by cyanidation, 95.4% of the silver was extracted from the oxidized tetrahedrite concentrate after 96 hours. This result is in excellent agreement with the fact that silver jarosite was not formed during the PLATSOL<sup>®</sup> process.

Another option, consistent with the objective of finding an alternative to cyanide, would be to leach the PLATSOL<sup>®</sup> residue with thiosulphate: as we recall it, the Patera process was applied in 1858 at Joachimsthal to dissolve silver chloride using  $\text{Na}_2\text{S}_2\text{O}_3$  [1]. One single test was carried out to leach silver from the PLATSOL<sup>®</sup> residue using ammonium thiosulphate: in 6 hours at room temperature, 87.5% of the silver was dissolved in 40 g/L thiosulphate solution.

#### APPLICATION OF THE PLATSOL<sup>®</sup> TO PREG-ROBbing GOLD ORES

From the discussions earlier, it is apparent that the gold chloro-complex is preg-robbed by some carbon species under typical PLATSOL<sup>®</sup> conditions and, therefore, it is expected that the PLATSOL<sup>®</sup> process should not be used on preg-robbing gold ores.

However, there might be cases where PLATSOL<sup>®</sup> could have a role to play. If we assume that in preg-robbing ores the formation of the gold chloro-complex proceeds unimpeded, and that the complex is adsorbed on the preg-robber matter, a

significant proportion, if not all the gold in the autoclave discharge would then be present as adsorbed species on the preg-robber. If a means could be found to separate the preg-robbers from the autoclave discharge, we could produce a high grade gold concentrate on site and this could be advantageous.

To test the concept, a preg-robbing refractory gold concentrate from Africa, assaying 18.4% Cu, and 208 g/t Au was submitted to a standard PLATSOL<sup>®</sup> test. As expected, 99.8% of the copper was dissolved, but, because of the presence of preg-robbers, only 0.2% of the gold was present in solution in the autoclave discharge.

The PLATSOL<sup>®</sup> residue was then submitted to a flotation test whereby the carbonaceous component was collected using fuel oil and frother. The gold balance is presented in Table 10.

After a single test, the results indicated that 75% of the gold could be concentrated in 26% of the weight (almost a three-fold upgrading), or 90% of the gold in 46% of the weight (almost two-fold upgrading). It is quite likely that the grade could be increased by cleaning the rougher concentrate, and/or the recovery improved by optimization of the reagent regime. A higher grade concentrate could be burned and gold metal recovered on-site, instead of selling the concentrate and having to pay smelter charges and transportation costs. These results indicate that further work in this area is warranted.

#### ENGINEERING IMPLICATIONS OF THE PLATSOL<sup>®</sup> PROCESS FOR GOLD RECOVERY

Typical operating conditions for the PLATSOL<sup>®</sup> process (225°C, 100 psi  $\text{O}_2$ , acidic pulp) are very similar to conditions used in the gold industry for refractory gold ores (i.e. Goldstrike, Nevada), and, therefore, similar equipment could be used (brick-lined autoclave with a steel shell). However, PLATSOL<sup>®</sup> solutions also contain 3-10 g/L Cl, which normally precludes the use of lead liner underlying the bricks to protect the steel shell. Recent laterite projects in Australia, which operate at even higher temperatures (~250°C), and contain (for some) very high levels of chloride, have resorted to the use of titanium-clad autoclaves. The Goldstrike autoclaves have also recently been converted from brick to titanium lining, to increase their working volume. As another alternative for the PLATSOL<sup>®</sup> process, it is recommended to use brick lined autoclaves with a polymeric membrane instead of the lead liner between the steel shell and the brick lining. A commercial example of such application is given by the Macraes mine in New Zealand, where the polymeric membrane has been operating for several years with complete success [11,12]. Polymeric membranes are also being developed for the laterite industry. In addition, the demonstration autoclave that has been built by Phelps Dodge in Arizona to process chalcopyrite concentrates under similar conditions (225°C, 100 psi  $\text{O}_2$ , acidic pulps) incorporates a polymeric membrane, and this will hopefully confirm the suitability of such equipment for PLATSOL<sup>®</sup> applications.

The remainder of the circuit (copper SX, thickeners, filters, tanks) must be

Table 10 Flotation of graphitic carbon from PLATSOL<sup>®</sup> residue

FRACTION	Wgt (%)	Au	
		g/t	%Recovery
Rougher 1	26.6	1132	75.4
Rougher 2	19.7	290	14.2
Total Rougher	46.3	774	89.6
Rougher Tail	53.7	77	10.4
PLATSOL <sup>®</sup> Residue	100	399	100



constructed to handle the acidic chloride solution, but that is a manageable task.

## CONCLUSIONS

The PLATSOL® process was developed to leach the base metals and precious metals (including gold) from NorthMet concentrate in a single step. The applicability of the process was later extended to other Cu-Ni-PM concentrates, to Cu-Au concentrates, and then to refractory (but non preg-robbing) gold concentrates.

Because of the high costs associated with operating high temperature autoclaves, the PLATSOL® process cannot be applied economically to the treatment of low grade free gold ores; in those cases, if cyanide use is banned, other alternatives have to be developed. However, the PLATSOL® process can offer a viable non-cyanide alternative in several instances, such as:

- gold-containing concentrates with valuable by-products such as Cu, Ni and PGM's
- chalcopyrite, enargite or other copper sulphide concentrates where hydrometallurgical techniques are considered (i.e. Phelps Dodge)
- refractory, non preg-robbing ores where an oxidation stage is required
- gold concentrates where arsenic stabilization is a critical issue

Once gold has been solubilized in the autoclave under PLATSOL® conditions, various means exist to recover it from solution prior to neutralizing the acid. NaSH precipitation is well proven, but requires a solid/liquid separation stage on acidic chloride solutions. Activated carbon appears as a natural option, in particular when used as carbon-in-pulp, but the challenge is presently to develop a suitable regeneration process. Ion exchange resins also appear promising, but further work is warranted for the elution and regeneration stages.

Although the PLATSOL® process does not seem to be well suited for preg-robbing concentrates and high silver concentrates, the formation of chloro-complexes under PLATSOL® conditions could open the door to novel means of

recovering the gold and the silver, not from the PLATSOL® liquor but rather from the residue, without using cyanide.

## REFERENCES

1. K. Liddel, Handbook of non-ferrous metallurgy (New York, NY: McGraw-Hill Publishing Company, 1950).
2. G. L. Putnam, Chlorine as a Solvent in Gold Hydrometallurgy (Engineering Mining Journal, Vol. 145, No. 3, 1944), 70-73.
3. M. A. Diaz, G.H. Kelsall, N.J. Welham, Electrowinning coupled to Gold Leaching by Electrogenerated Chlorine. I. Au(III) - Au(I)/Au Kinetics in Aqueous Cl<sub>2</sub>/Cl<sup>-</sup> Electrolytes, (Journal of Electrochemical Chemistry, Elsevier, 361, 1993), 25-38.
4. D. Huahua, L. Xianguang, Chloride Roasting of a Complex Gold Ore and Treatment of Chloride Fume for Precious-Metal Recovery-Experimental Results, (Trans. Institution of Mining and Metallurgy, Section C, 96, March 1987), C44-C46.
5. W. E. Dunn, Jr., Chlorine Extraction of Gold, (Gold, Silver, Uranium and Coal - Geology, Mining, Extraction and the Environment, M. C. Fuerstenan, B. R. Palmer, Ed., AIME, NY, 1983), 174-188.
6. J. A. Eisele et al, Gold Transport by Complex Metal Chloride Vapors, (USBM Report of Investigations 7489, 1971).
7. C. W. A. Muir, R. D. Stett, C. J. Priddle, , Extraction of Gold from Antimony-Rich Slag by Chloride Metallurgy, (Hydrometallurgy - Research, Development and Plant Practice, Osseo-Asare Ed., AIME, 1982), 825-838.
8. G. P. Demopoulos, V. G. Papangelakis, Acid Pressure Oxidation of Refractory Gold Mineral Carriers, International Symposium of Gold Metallurgy, 1987, ed. R. S. Salter, D. M. Wyslouzil, G. W. McDonald (Winnipeg, Canada), Pergamon Press, 341-357.
9. L. S. Pangum, R.E. Browner, Pressure Chloride Leaching of a Refractory Gold Ore, (Minerals Engineering, Vol. 9, No. 5, 1996), 547-556.
10. K. G. Thomas, Research, Engineering Design and Operation of a Pressure Hydrometallurgy Facility for Gold Extraction, (PhD. Thesis, Technische Universiteit Delft, 1994).
11. V. J. Ketcham, J. F. O'Reilly, W. D. Vardill, The Lihir Gold Project; Process Plant Design, (Minerals Engineering, Vol. 6, No. 8-10, 1993) 1037-1065.
12. G. L. Simmons et al, Pressure Oxidation Problems and Solutions: Treating Carbonaceous Gold Ores Containing Trace Amounts of Chlorine (Halogens), (Mining Engineering, January, 1998), 69-73.
13. C. A. Fleming et al, A Process for the Simultaneous Leaching and Recovery of Gold, Platinum Group Metals and Base Metals from Ores and Concentrates, (Nashville, TN: TMS Annual Meeting, EPD, 2000).
14. C. J. Ferron et al, PLATSOL® Treatment of the NorthMet Copper-Nickel - PGM Bulk Concentrate - Pilot Plant Results, (Perth, Western Australia: Alta Nickel Cobalt 2001 Conference, May, 2001).
15. D. B. Dreisinger et al, The Hydrometallurgical Treatment of Base Metal Sulphide Concentrates Containing Precious and Platinum Group Metals, (Melbourne, Australia: Minprex 2000, September 2000).
16. J. Quing, M. J. Nicol, "Thermodynamics and Kinetics of the Dissolution of Gold Under Pressure Oxidation Conditions in the Presence of Chloride," Chloride Metallurgy 2002, 32nd Annual Hydrometallurgy Meeting, Vol. 1, ed. E. Peek, G. VanWeert, (Montreal, Quebec: CIM, 2002), 41-54.
17. J. N. Greaves, G. R. Palmer, W. W. White III, The Recovery of Gold from

Refractory Ores by the Use of Carbon-in-Chlorine Leaching, (Journal of Metals, Sept., 1990), 12-14.

18. J. Avraamides, G. Hefter, C. Budeselic, The Uptake of Gold from Chloride Solutions, (Proc. Aus IMM, Vol 290, 1982), 59-62.

19. H. C. Hughes, H. G. Linge, The Kinetics of Gold Loading from Gold (III) Chloride Solutions onto Fresh Activated Coconut Carbon, (Hydrometallurgy, 22, 1989), 57-65.

20. J. M. W. Mackenzie, Cognis AuRiX® 100 Resin for Gold Extraction - Engineering Cost Study and Pilot Plant Investigations, ed. A. Taylor (Perth, Australia: ALTA 2001).

---

## CONTACT INFORMATION

Email us at [minerals@sgs.com](mailto:minerals@sgs.com)

[WWW.SGS.COM/MINERALS](http://www.sgs.com/minerals)

© 2011 SGS. All rights reserved. The information contained herein is provided "as is" and SGS does not warrant that it will be error-free or will meet any particular criteria of performance or quality. Do not quote or refer any information herein without SGS' prior written consent. Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.