

## Cyanidation of a pyrrhotite-bearing gold ore

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Received 30 July 2002; accepted 21 November 2003

### ABSTRACT

The Musselwhite Mine in Canada processes a free milling gold ore at 5.5-5.8g/t Au and 4.2% pyrrhotite. A laboratory investigation was conducted to improve cyanidation. The pyrrhotite was determined to be 50% monoclinic and 50% hexagonal. A leach using 8ppm dissolved oxygen yielded only 82.3% gold extraction with a 0.29kg/t NaCN consumed. The addition of lead nitrate, directly to the leach, showed 94.2% gold extraction with only 0.16kg/t NaCN consumption. A gold extraction of 95.0% was obtained by adding oxygen with lead nitrate. The laboratory results were found to be similar to current plant practice. Plant data indicated that the enhancement of leaching kinetics has resulted in a 0.61% increase of gold recovery, from 95.20% in 1999 to 95.81% in 2000. Benefits of the oxygen system were more pronounced in the hot summer months when higher slurry temperatures depleted dissolved oxygen content and pyrrhotite is more reactive. Other modifications include the installation of cone spargers. The results of July 2000 versus those of July 1999 displayed a 2.0% improvement in recovery with the use of oxygen (i.e. a reduction of 0.08g/t Au in the leach residue). In 2000, the improvement of gold recovery represented an additional gross revenue of \$CDN0.5 Million (€0.304 Million). Cyanide consumption decreased slightly by approximately 8%. © 2003 SDU. All rights reserved.

Keywords: Gold; Cyanide; Leaching; Lead nitrate

### 1. INTRODUCTION

Gold deposits containing sulphide minerals are common in North America. Sulphide minerals influence gold leaching kinetics and reagent consumption. The effect of sulphide minerals and their dissolved ions on the leaching rate of gold has been investigated in the presence of oxygen (Yen and Aghamirian, 2002). The paper suggested that sulphide minerals could be divided into three groups depending upon their effect on gold leaching: a group that has a negative effect (stibnite, chalcocite and pyrrhotite); a group that neither seriously reduces nor greatly enhances gold leaching (pyrite, chalcopyrite, arsenopyrite and sphalerite); and, a group that improves gold leaching (galena).

The role of metal-cyanide species in leaching gold from a copper concentrate has been studied recently (Rees and van Deventer, 1999). It was found that  $\text{Cu}(\text{CN})_4^{3-}$  leaches gold. Various cyanidation studies demonstrated that a careful selection of leaching parameters is critical to the gold leaching operation with cyanide in the presence of sulphide minerals (Deschênes *et al.*, 2001a). These parameters depend on the mineralogical composition of the ore. The results clearly demonstrated that oxygen by itself cannot alleviate the negative effect of sulphide minerals and has to be used with lead nitrate.

Recent studies investigated the effect of pyrrhotite on cyanidation (Dunn *et al.*, 1995; Lehmann *et al.*, 2000). An electrochemical study indicated that pyrrhotite oxidation is much slower than the cyanidation of gold and is an unlikely reaction to significantly consume dissolved oxygen and cyanide (Dunn *et al.*, 1995). Pyrrhotite is in much higher concentration than gold in a gold ore. The oxygen requirement by the pulp will depend on the concentration of pyrrhotite in the ore and the degree of oxidation of its surface.

A study on hexagonal pyrrhotite indicated a very low solubility in aerated cyanide solutions (Linge, 1995). The transformation of pyrite to pyrrhotite, using pyrolysis, indicated that the cyanide consumption gradually decreases with an increase in the pyrrhotite content of the sample (Browner and Lee, 1998). This finding means that pyrrhotite is less reactive than pyrite in a cyanide solution. The reactivity of pyrrhotite

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would depend upon the degree of oxidation of its surface. The study of the dissolution rate of hexagonal and monoclinic pyrrhotite showed that monoclinic pyrrhotite is more reactive (Lehmann *et al.*, 2000). It is difficult to be entirely sure that synthesised minerals have the same reactivity as natural minerals.

Sulphide minerals have a preg-robbing capacity. Preg-robbing is the removal of dissolved gold by a solid. An XPS and SEM study characterized the form of gold on sulphide minerals (Jean and Bancroft, 1985). A comprehensive study of the preg-robbing property of minerals, using Mössbauer spectroscopy indicated that gold cyanide is reduced on the surface of sulphide minerals (Adams *et al.*, 1996). The preg-robbing phenomenon was examined for materials with a high concentration of chalcopyrite and pyrite (Rees and van Denventer, 2000). The concentration of free cyanide proved to be critical to avoid the preg-robbing of gold by sulphide minerals. In practice, this means that below the critical concentration of cyanide, gold extraction decreases significantly.

The Musselwhite Mine plant, originally designed at 3,300tpd, processes a free milling gold ore containing pyrrhotite as the primary sulphide, at a present throughput of 3,650t/d. The ore is crushed in two stages, using a 1m x 1.4m jaw crusher and 2.1m super heavy-duty cone crusher. The -1.9cm fine ore is ground in a conventional rod and ball mill circuit. Gold is recovered by gravity separation prior to cyanidation. Cyanide bearing process water, lime and lead nitrate is added at the rod mill. The grinding thickener underflow is pumped to the cyanidation circuit where cyanide and lime are stage added, as required. Oxygen is sparged into leach tanks No. 1 and No. 2, while compressed air is added to the remaining two tanks. The leach slurry flows by gravity to the CIP circuit. A schematic diagram of the cyanidation circuit is illustrated in Figure 1. The retention time of the leaching circuit is important for the performance of the plant.

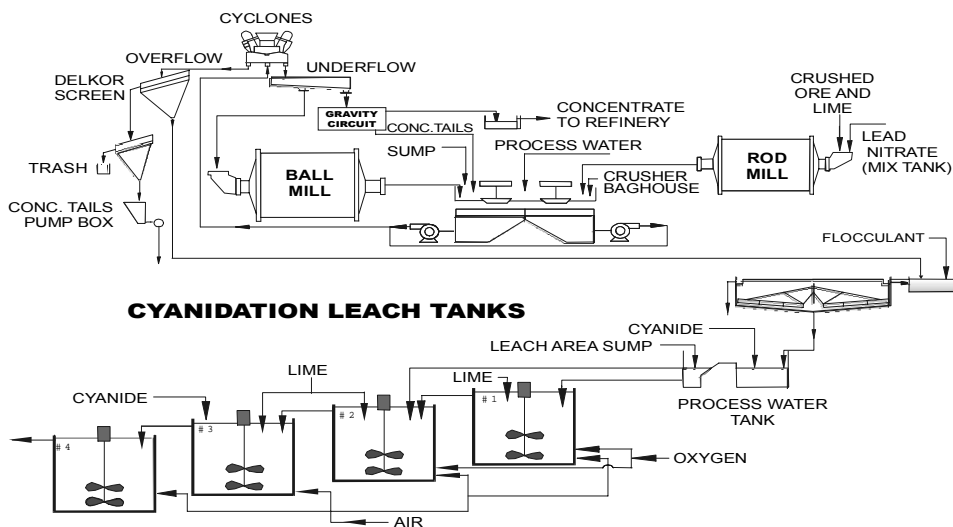


Figure 1. Schematic diagram of Musselwhite Mine grinding and leaching circuit

The presence of pyrrhotite in gold ores is known to have a negative impact on the dissolution of gold and on the consumption of cyanide. This report presents the results of a cyanidation study on a sample containing pyrrhotite as the only cyanide. The purpose of the study was to evaluate the detrimental effect of pyrrhotite as a cyanide and to determine the best cyanidation conditions to alleviate its negative impact. Plant data are also presented to discuss the improvement made since the study was conducted.

## 2. EXPERIMENTAL

### 2.1. Material

A sample of rod mill feed, weighing 43.5kg, was air dried at room temperature for 24 hours crushed and screened into 2 separate lots of +149 $\mu$ m, and -149 $\mu$ m. The +149 $\mu$ m fraction was ground to 100% -149 $\mu$ m using a ceramic ball mill and steel balls. The coarse fraction is ground separately and mixed with the fine fraction to make sure that the sulphideminerals are correctly ground.

The two fractions were mixed and ground to 73.9% -74 $\mu$ m, tumbled for two hours using a drum tumbler and divided into 1000g lots using a rotary separator. The  $d_{74}$  was used because it was the same parameter used by the plant.

The gold content, determined in triplicate by fire assay, is 5.38g/t. The average calculated gold content of the overall sample (obtained from all the tests) is 5.75g/t with a variance of 0.05. The mineralogy was determined by quantitative SEM-based image analysis. The ore consists largely of gangue minerals. Clinocllore ((Mg,Fe)<sub>5</sub>Al(Si<sub>3</sub>Al)O<sub>10</sub>(OH)<sub>8</sub>), grunerite ((Fe,Mg)<sub>7</sub>Si<sub>8</sub>O<sub>22</sub>(OH)<sub>2</sub>), phlogopite (KMg<sub>3</sub>Si<sub>3</sub>AlO<sub>10</sub>(F,OH)<sub>2</sub>) and almandine (Fe<sub>3</sub>Al<sub>2</sub>(SiO<sub>4</sub>)<sub>3</sub>) represent 62% and quartz and tremolite (Ca<sub>2</sub>(Mg,Fe)<sub>5</sub>Si<sub>8</sub>O<sub>22</sub>(OH)<sub>2</sub>) 30% (Table 1). There is 4.2% pyrrhotite, 2.5% magnetite (Fe<sub>3</sub>O<sub>4</sub>) and 0.7% ilmenite (FeTiO<sub>3</sub>); pyrite (FeS<sub>2</sub>) and chalcopyrite (CuFeS<sub>2</sub>) occur as traces. The pyrrhotite was found to be 50% hexagonal and 50% monoclinic, using XRD, which is a semi-quantitative method. The cyanidation tests, performed on finely ground material (89% -37µm), indicated that 97.8% of the gold is leachable (0.12g/t Au in the tails; performed in duplicate). The remaining gold is probably locked in sulphide minerals. The chemical analysis indicated no detrimental elements such as tellurium, bismuth or antimony.

## 2.2. Equipment and experimental procedure

The lime, sodium cyanide, lead nitrate and oxygen were all certified reagent grade chemicals. Distilled water was used to pulp the ore. The gold-leaching cell is made of glass, with a capacity of two litres. The tests were performed on a pulp of 50% weight (1000g of ore with 1000ml of solution). Most of the cyanidation tests were carried out with a grind size at 73.9% -74µm and 100% passing 149µm.

Table 1  
 Analysis of the pyrrhotite-gold ore

Chemical Analysis (%)		Mineralogical Analysis (%)
Au	5.38g/t	Major phases: Clinocllore, Grunerite, Phlogopite and Almandine: 62.4 Quartz and Tremolite: 30.2
Ag	0.94g/t	
Si	26.0	
Fe	20.3	
Al	4.29	Minor phases: Pyrrhotite: 4.2 Magnetite: 2.5 Ilmenite: 0.7
Ca	1.99	
Mg	1.73	
S	1.62	
Ni	0.008	Trace: Pyrite Chalcopyrite
Zn	0.013	
Pb	0.004	
Cu	0.013	
Sb	<0.001	
Te	<0.001	

The details of experimental procedure are described in a previous report (Deschênes *et al.*, 2002). The cyanidation and the pre-leaching used the same pulp. The pH was controlled by lime addition. The cyanidation tests were 32h or 48h in duration.

Relative to the average concentration, the accuracy of free cyanide concentration was ±10%. The gold extraction was based on the gold content in the leached tails compared with the gold content in the head sample. To determine the mass balance in each experiment, the gold concentration of the calculated head was obtained by adding the gold content in the tails, the liquid samples, the leachate and the wash solution. The gold concentrations in solution were used to deduce the extraction kinetics plots. Lead nitrate was not added to the pre-leaching unless specified.

The leach solution and wash solutions were titrated for free cyanide with silver nitrate and rhodamine as an indicator, and then assayed for gold and base metals (Fe, Cu) by atomic absorption spectroscopy. The accuracy for cyanide titration was estimated at ±5%. The calculation of cyanide consumption was based on 66% recycling of the leach solution. Thiosulphate was determined using gradient ion chromatography.

Three experimental conditions were run in duplicate to evaluate the reproducibility. In general, a good reproducibility was obtained. The results showed that gold extraction was reproducible to 0.08g/t or less. The variation in cyanide consumption was 0.02kg/t for the ore ground to 74% -74µm and 0.09kg/t for the finely ground material.

### 3. RESULTS

#### 3.1. Effect of pre-leaching

The oxidation of pyrrhotite in a basic media yields iron hydroxide and sulphate according to Equation 1.



The pyrrhotite in this ore, which is 50% hexagonal and 50% monoclinic, is not very reactive. Only 46ppm of sulphate was formed in 8 hours while thiosulphate gradually increased to 37ppm; thiosulphate being the intermediate oxidation product. Because the oxidation of sulphide was slow, thiosulphate was also formed according to Figure 2. A very reactive pyrrhotite would require a pretreatment because its oxidation would inhibit the reaction of gold with oxygen. These results are in agreement with the plant practice that does not use a pretreatment prior to cyanidation.

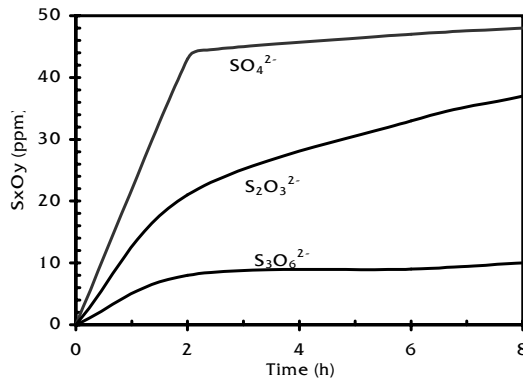


Figure 2. Kinetics of the oxidation of soluble sulphides during the pre-leaching of a pyrrhotite-bearing gold ore (pH 11.2, 8ppm O<sub>2</sub>)

Figure 3 illustrates the results of the tests to evaluate the effect of pre-leaching with oxygen enrichment or lead nitrate addition. Straight cyanidation showed slow leaching kinetics with an overall gold extraction of 82.3% in 48 hours with a cyanide consumption of 0.28kg/t. The increase of dissolved oxygen concentration to 16ppm significantly enhanced the leaching kinetics and the gold extraction reached 93.7% with a cyanide consumption of 0.29kg/t. Furthermore, the leaching kinetics was improved by adding 200g/t of lead nitrate directly to the leach with an overall gold extraction of 94.2% within 32 hours. A 20% reduction of the cyanide consumed (0.29kg/t to 0.23g/t) was observed. Considering the accuracy of titration and the accuracy of control and the reproducibility, this difference is significant.

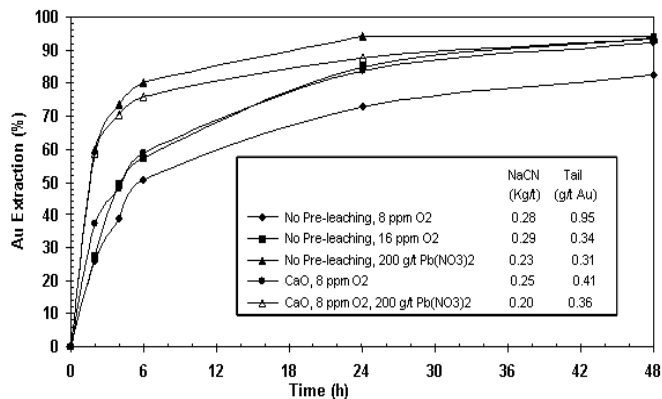
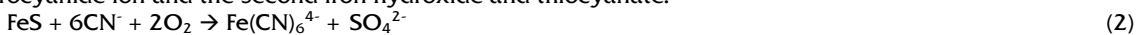


Figure 3. Effect of pre-leaching and lead nitrate addition on the leaching of a pyrrhotite-bearing gold ore (Cyanidation: pH 11.2, 380ppm NaCN, 8ppm O<sub>2</sub>, 48h)

The reaction of pyrrhotite with cyanide is expressed in Equations 2 and 3. The first one yields ferrocyanide ion and the second iron hydroxide and thiocyanate:



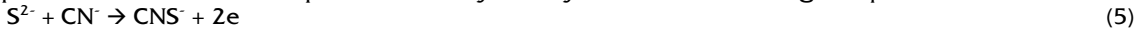
Under these leaching conditions, there was only 2-3ppm iron in solution. Increasing the dissolved oxygen concentration in the slurry reduced the formation of thiocyanate (Eq. 3). The increase of the dissolved oxygen level did not improve the cyanide consumption. The amount of cyanide consumed by the formation of cyanate increased with the higher dissolved oxygen concentration. Although the chalcopyrite content of this ore is low, its contribution to the cyanide consumption was 10% to 20% using the concentration of copper dissolved and complexed by cyanide. The estimate is based on the copper in solution.

A pre-leaching with lime was better than the straight cyanidation, with a 92.4% gold extraction and 0.25kg/t cyanide consumed (Figure 3). The reduction in the cyanide consumed is due to the oxidation of pyrrhotite during pre-leaching according to Equation 1. Adding lead nitrate to the pre-leach (8 hours being the retention time of a tank) improved the leaching kinetics but not enough to surpass the results obtained by adding lead nitrate directly during cyanidation. The lowest cyanide consumption, which is 0.20kg/t NaCN, was achieved by using a pre-leach with lead nitrate.

The mechanisms by which pyrrhotite dissolution and oxidation proceed are complicated. A general reaction describing the overall dissolution and oxidation of pyrrhotite can be expressed according to Equation 4 (Deschênes *et al.*, 2001b)



where  $\text{Fe}_{1-x-y}\text{S}$  represents the iron deficient surface layer.  $\text{Fe}_{1-x}\text{S}$  is used to illustrate the loss of iron. Sulphur in the iron deficient sulphide surface layers may be leached according to Equation 5:



The reaction of pyrrhotite is inhibited by the formation of iron hydroxide layer and by the presence of lead hydroxide or oxide on the surface of pyrrhotite particles (Deschênes *et al.*, 2000).

### 3.2. Effect of lead nitrate addition

The use of lead nitrate increases the gold dissolution kinetics considerably, as shown in Figure 4. A gold extraction of 93.9% was obtained in 24 hours with the addition of 50g/t lead nitrate compared to 78.1% without lead nitrate. As indicated by the previous work, lead nitrate favours the dissolution of gold by acting at the surface of gold particles to prevent the formation of a passive layer of sulphide (gold sulphide) (Deschênes *et al.*, 2000). An increase in  $\text{Pb}(\text{NO}_3)_2$  concentration to 100g/t further improves the leaching kinetics, although the overall gold extraction remains about the same (93.1% vs. 93.9%). Increasing lead nitrate beyond 100g/t brought a small benefit in terms of cyanide consumption and gold recovery. A 25% reduction of cyanide consumption was observed, and the gold loss seems to be slightly lower at 0.31g/t in the leach residue.

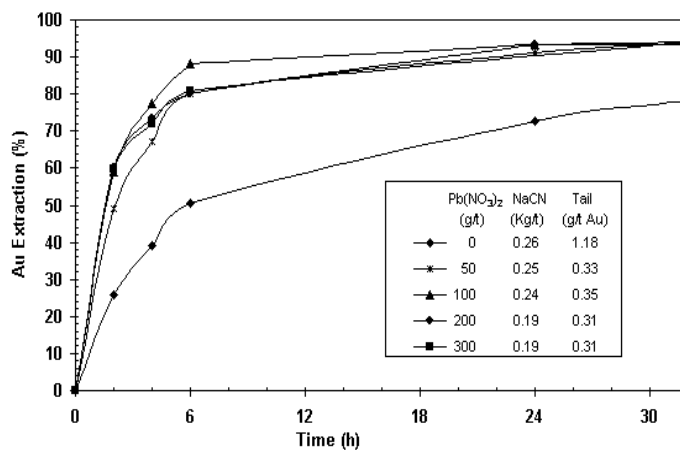


Figure 4. Effect of lead nitrate addition on the leaching of a pyrrhotite-bearing gold ore (Cyanidation: pH 11.2, 380ppm NaCN, 8ppm  $\text{O}_2$ , 32h)

Figure 5 illustrates the reaction of cyanide with chalcopyrite and pyrite. There is a reduction in the thiocyanate formed, in the copper dissolved and the cyanide consumed with the increase of the lead nitrate addition. A 25% reduction in cyanide consumption was achieved from 0 to 200g/t  $\text{Pb}(\text{NO}_3)_2$ . The thiocyanate formation decreased by 61ppm and 10ppm, respectively. Beyond 200g/t lead nitrate addition, thiocyanate and copper continue to decrease while the cyanide consumption remains constant. Thus, the reduction in thiocyanate and copper concentrations indicates that lead nitrate decreases the reaction of cyanide with pyrrhotite and chalcopyrite.

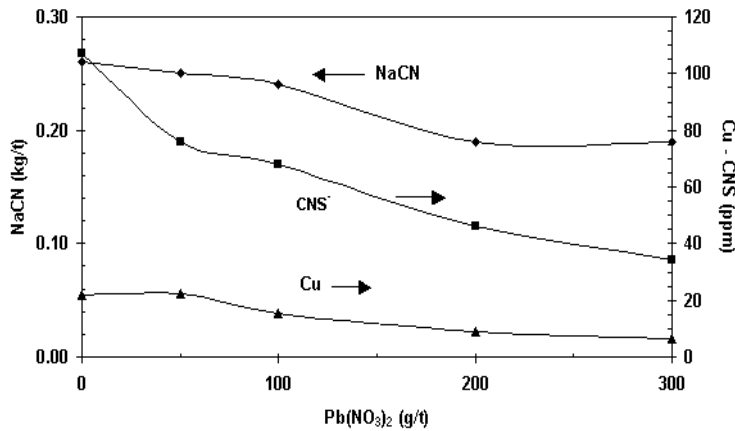


Figure 5. Curves for copper dissolution, thiocyanate formation and cyanide consumption during the cyanidation of a pyrrhotite-bearing gold ore as a function of lead nitrate addition

The mass balance calculation on cyanide showed that the cyanide consumed by the formation of thiocyanate was reduced by more than 55% (from 35% to 15%). The cyanide consumed by the formation of copper cyanide complex was also reduced by more than 50% (from 20% to 8%). The contribution of iron to cyanide consumption is very low, ranging from 2-6%. However, the cyanide consumption remains constant when the loss created by the oxidation of cyanide to cyanate equals the reduction of cyanide consumed by sulphide minerals.

### 3.3. Effect of pH, cyanide concentration and reproducibility

Under a constant dissolved oxygen concentration (8mg/l), a reduction in pH, from 11.2 to 10.2, resulted in the leaching kinetics being almost the same in the first four hours. The overall gold extraction was about the same after 32 h (94.2% - 94.6%, tail at 0.29-0.31g/t Au). However, a pH of 10.2 was detrimental on the cyanide consumption that increased by 17%. It is believed that the formation of iron hydroxide is enhanced at higher pH. This iron hydroxide layer would reduce the reaction of pyrrhotite with cyanide.

The effect of free cyanide concentration was evaluated between 150ppm and 510ppm NaCN. The results are illustrated in Figure 6. The use of 290ppm to 510ppm NaCN resulted in similar overall gold extractions (93.5-94.2%, tails at 0.31-0.35g/t Au). The dissolution rate increases with the free cyanide concentration in the first 8 hours but varies little after 12 hours in this range of concentration. Cyanide consumption decreased by 35% (0.08kg/t, from 0.23kg/t to 0.15kg/t with 510ppm and 290ppm NaCN, respectively). A concentration below 290ppm NaCN resulted in an increase of the gold content in the leach residue at 0.42g/t.

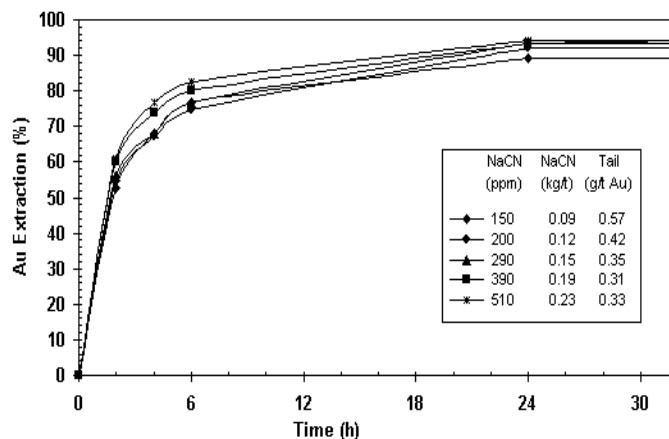


Figure 6. Effect of the free cyanide concentration on gold leaching from a pyrrhotite-bearing gold ore (Cyanidation: pH 11.2, 8ppm O<sub>2</sub>, 200g/t Pb(NO<sub>3</sub>)<sub>2</sub>, 32h)

Lowering the concentration of sodium cyanide to 200ppm caused a ~2% reduction in gold recovery (tail increasing by ~0.1g/t Au). Below a certain concentration of free cyanide, the leaching efficiency started to decrease significantly. This phenomenon was even more important for a sulphide-bearing gold ore containing copper. A 30% reduction in gold extraction was observed below the critical level of free cyanide (Deschênes and Fulton, 1998). The lower performance of cyanidation is related partly to the lower gold leaching rate below the critical level. A preg-robbing phenomenon is probably involved in this reaction as well. The preg-robbing property of pyrrhotite would begin to be more important below a certain concentration of free cyanide. Previous work on the preg-robbing properties of sulphide minerals demonstrated the relation between the preg-robbing effect and the concentration of free cyanide in solution (Rees and van Denventer, 2000).

### 3.4. Effect of oxygen

The dissolved oxygen content of the pulp was also controlled at 8ppm and 16ppm to evaluate the effect on the gold extraction. Figure 7 illustrates the leaching kinetics at two different levels of dissolved oxygen. There is only a slight improvement in the leaching kinetics at 16ppm oxygen. The gold content in the leach residue is lower by 0.08g/t Au (0.23g/t Au) at 16 ppm oxygen, compared to 0.31g/t Au at 8ppm oxygen. The cyanide consumption is about the same for both conditions.

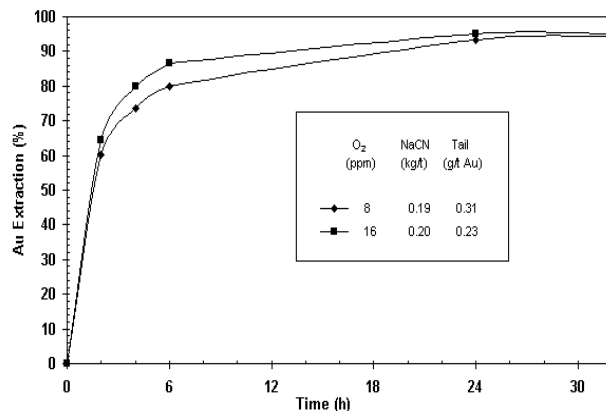


Figure 7. Effect of oxygen on gold leaching of a pyrrhotite-bearing gold ore (Cyanidation: pH 11.2, 200g/t Pb(NO<sub>3</sub>)<sub>2</sub>, 32h)

At the laboratory scale, it is impossible to figure out the economics of using oxygen vs. the additional in gold extracted because of the tremendous scale factor and the lack of accuracy in the oxygen consumed. In most of the gold plants where oxygen is used to improve the gold extraction, the cost of oxygen is not a major component of production costs. Consequently, the extra gold recovered is economical. These results indicate that injecting oxygen in the leach tanks is beneficial.

### 3.5 Plant data

The addition of oxygen to cyanidation proved to be correct and resulted in an increase of gold extraction. The faster leaching kinetics are identified by the oxygen trial plot. The gold leaching kinetics were higher (Figure 8). Consequently, the overall gold extraction increased. The gold content of the leach residue was an average of 0.255g/t Au in 1999 and 0.269g/t Au in 2000 from head grades of 5.61 and 6.47g/t Au respectively. Had the head grades been comparative for both years, oxygen addition would have resulted in a 0.065g/t Au decrease. Cyanide consumption decreased slightly by approximately 8%. Other modifications prior to oxygen addition include the installation of cone spargers in the leach system and an automatic cyanide titrator installation in the spring of 2001 for better control of free cyanide concentrations.

## 4. DISCUSSION

The determination of gold leaching parameters for the treatment of this ore is a good opportunity to demonstrate the effect of pyrrhotite on cyanidation. Indeed, this ore contains only pyrrhotite, as the cyanide, at a concentration of 4.2%. The pyrrhotite occurs as 50% monoclinic and 50% hexagonal. The

presence of monoclinic pyrrhotite, which is the more reactive form (Lehmann *et al.*, 2000), did not generate a problem of high cyanide consumption.

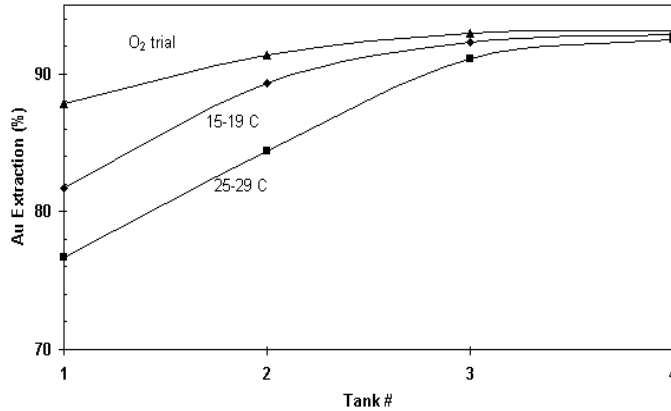


Figure 8. Oxygen trial at Musselwhite Mine

Cyanidation conducted only with the addition of oxygen at a regular dissolved oxygen concentration equivalent to air sparging results in low gold leaching kinetics. The problem is not only related to the competition of gold and pyrrhotite for oxygen but also to the formation of a passive layer on the gold particles. These problems can be effectively overcome by the addition of lead nitrate. Other lead compounds such as lead acetate would have the same beneficial effect because the role is assumed by the lead ion. In this case, the low content of pyrrhotite makes it possible to add the lead salt directly to the grinding circuit.

The enhancement of gold dissolution, by the formation of gold/lead galvanic couples, is another reason for the faster leaching kinetics (Deschênes *et al.*, 2000). On a 32-hour basis, the absence of lead nitrate in the gold leaching system means a significant decrease in the gold extraction of 16%. The plant confirmed this result. A shortage of lead nitrate in the plant resulted in the same low gold extraction. In June 1999, the lead nitrate system was taken off line for maintenance, which resulted in an immediate drop in recovery to 82.7%. Recovery returned to normal levels when the system was reactivated.

Optimum leaching conditions obtained at pH 11.2, lead nitrate addition at 200g/t and with an average free cyanide concentration of ~380ppm NaCN were the same for the laboratory and the plant. The laboratory study indicated that pre-leaching is not required and lead nitrate can be added directly in the grinding circuit. A lead nitrate addition higher than 200g/t would not be beneficial and would only increase the reagent costs. The addition of oxygen was under evaluation at the time that the project was conducted. Oxygen enrichment of the pulp from 8ppm to 16ppm yielded an improvement in gold extraction. The gold content of the leach residue was decreased from 0.31g/t to 0.23g/t.

In spite of the low consumption of cyanide observed in the laboratory experiments (i.e., 0.19kg/t vs. 0.35kg/t in the plant), the laboratory study indicated a cyanide consumption in the same range for the ores containing 7% pyrrhotite and 3.7% pyrrhotite (0.17-0.18kg/t NaCN) (Deschênes *et al.*, 1999). The cyanide consumption reported by Musselwhite Mine accounts for the decomposition of cyanide in the Carbon-In-Pulp circuit and during elution. There is natural degradation of cyanide that occurs during the recycling of the solution.

Considering about 25% of the cyanide consumed by the plant not being related to leaching (decomposition in the CIP and used in elution), the difference between the laboratory results and the plant consumption is only 0.07kg/t (20%). Considering that laboratory results cannot be exactly the same than plant data for number of reasons (up scaling factor, difference in the nature of the feed, etc.), the cyanide utilisation of the plant appears to be well controlled. The laboratory results also indicated a reduction of 0.08g/t Au in the leach residue.

Plant data indicated an enhancement of the gold leaching kinetics (Figure 8). The improvement has resulted in a 0.61% increase of gold recovery, from 95.20% in 1999 to 95.81% in 2000. Benefits of the oxygen system were more pronounced in the hot summer months when higher slurry temperatures depleted dissolved oxygen content and pyrrhotite is more reactive. The results of July 2000 versus those of July 1999 displayed a 2.0% improvement in recovery with the use of oxygen i.e. a reduction of 0.08g/t Au in the leach residue at comparable head grades. In 2000, the improvement of gold recovery represented an additional gross revenue of \$CND0.5 Million (€0.304 Million). Cyanide consumption decreased slightly by approximately 8%. Other modifications prior to oxygen addition include the installation of cone spargers in the leach system.



An automatic cyanide titrator was installed in the spring of 2001 for better control of free cyanide concentrations.

## 5. CONCLUSIONS

This ore contains 4.2% pyrrhotite of which 50% is monoclinic and 50% is hexagonal. Cyanidation performed with 8ppm dissolved oxygen resulted in low gold leaching kinetics and poor gold extractions. The addition of lead nitrate directly to gold leaching overcame this problem by increasing the gold extraction by 16% while reducing the cyanide consumption. Oxygen enrichment of the pulp was also very useful to improve the overall gold extraction. The maximum gold extraction was 95.0% (tail at 0.23g/t) and the cyanide consumption was found to be similar to that obtained in previous studies. The pyrrhotite produced a low cyanide consumption that was kept below 0.20kg/t. Preg-robbing of gold on pyrrhotite was observed for a free cyanide concentration of 150ppm NaCN. In spite of the low concentration of copper, its contribution to cyanide consumption was in the range of 10-20%. In 2000, the improvement of gold recovery at Musselwhite Mine represented an additional gross revenue of \$CND0.5 Million (€0.304 Million). Cyanide consumption decreased slightly by approximately 8%.

## ACKNOWLEDGMENTS

The authors wish to thank Placer Dome Technical Services Limited for its support and Dr. Jinxing Ji from Placer Dome Technical Services Limited for his participation and collaboration. Thanks are also extended to the CANMET staff: Jean Cloutier for the fire assay and other analysis, Dr. Rolando Lastra and Dr. John Wilson for the mineralogical analysis, and John Graham and Phil Mulvihill for the other analyses. We are also indebted to Dr. Dogan Paktunc and Dr. John Dutrizac for their editorial comments.

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