

# 'In-stope' leaching with thiourea\*

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## SYNOPSIS

*In situ* leaching tests with thiourea as the lixiviant were carried out in two worked-out stopes at the No. 6 shaft at Rand Leases Gold Mining Company. Dissolution rates of 0,9 and 0,7 g of gold per week per 100 m<sup>2</sup> of footwall area were achieved. A major disadvantage of the method seems to be the slow rate of dissolution of the gold, which is probably caused by poor contact and slow mass transfer between the lixiviant and the gold surfaces. Under full-scale application, the loss of lixiviant by leakage could also be a very important factor. Furthermore, the oxidation products of thiourea may 'poison' the activated carbon that is used for the recovery of the gold. The method may therefore be economically viable only in stopes that contain high values of residual gold.

## SAMEVATTING

Loogtoetse ter plaatse met tio-ureum as die loogmiddel is in twee uitgewerkte afbouplekke by skag nr. 6 van Rand Leases Gold Mining Company uitgevoer. Oplostempo van 0,9 en 0,7 g goud per week per 100 m<sup>2</sup> vloeroppervlakte is verkry. 'n Belangrike nadeel van die metode is blykbaar die stadige oplostempo van die goud wat waarskynlik veroorsaak word deur swak kontak en stadige massa-oordrag tussen die loogmiddel en die goudoppervlakte. Met 'n volskaalse toepassing kan die verlies van die loogmiddel deur lekkasie ook 'n baie belangrike faktor wees. Verder kan die oksidasieprodukte van tio-ureum die geaktiveerde koolstof wat vir die herwinning van die goud gebruik word, 'vergiftig'. Die metode kan dus net in afbouplekke met hoë goudrestewaardes lewensvatbaar wees.

## Introduction

Not all of the gold that is estimated, by sampling, to be present in a block of typical Witwatersrand ore reports to the reduction plant. Some of this 'unaccounted for' gold remains in the stopes either as fine grains of free gold or in the friable, gold-rich portion of the ore. An economic method for the recovery by a process involving dissolution of any of the gold remaining in the worked-out stopes would be beneficial to the gold-mining industry.

For a number of years, mined-out stopes on Witwatersrand gold mines have been swept by hand or vacuumed, and the recovered sweepings, which are transported to the surface for treatment, have proved to be rich in gold. Although much gold has been recovered by this simple but laborious process, significant quantities still remain in the worked-out stopes, which eventually close due to pressure.

During the past few years, attention has been given to the recovery of residual gold by the process of 'in-stope' leaching, in which the footwall, hangingwall, sidewalls, and support packs of the stope, together with any remaining broken rock, are sprayed with lixiviant to leach the fine accessible particles of gold from cracks and crevices. This method could also be used for the *in situ* leaching of broken ore that is too low in grade to justify its haulage to the surface and processing by the normal route.

Underground testwork has been carried out by various mining houses, but the results have been kept largely confidential. Mintek therefore initiated an investigation into in-stope leaching to obtain information on this potentially important method of gold recovery.

## Choice of a Suitable Site

Several possible sites for an in-stope leaching campaign were visited. In collaboration with the Management of the Rand Leases Gold Mining Company, a suitable area for testwork was identified at the no. 6 (Bantjes) shaft, which was re-opened in 1986.

Geological maps indicated that work in this area had stopped in 1971. The gold grade averaged about 10 g/t but was very inconsistent, and the grade in the particular stopes that were chosen was, according to the maps, between 2 and 3 g/t.

## Choice of Lixiviant

Several ligands, including cyanide, thiourea, thio-cyanate, chloride, polysulphide, and thiosulphate<sup>1</sup>, have been considered for gold leaching. Thiourea was chosen for the in-stope leaching tests since it offers the following advantages.

- (a) It is not toxic, and can therefore be safely used underground<sup>2,3</sup>.
- (b) Reasonable rates of leaching are reported, even under mild conditions<sup>4,5</sup>.
- (c) Thiourea has a high selectivity for gold, which should limit its consumption by the formation of complexes with other metals<sup>2</sup>.

## The Mechanism of Gold Leaching

Cyanide is by far the most widely used lixiviant for gold, and the mechanism of the cyanidation process is relatively well known. The dissolution of gold by solutions of cyanide and thiourea is compared in the following sections.

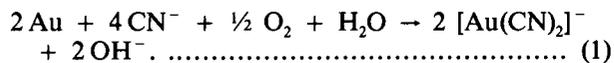
## The Dissolution of Gold in Cyanide Solution

The oxidation and complexing of gold in cyanide solution can be represented by the following reaction:

\* Presented at the Leaching Colloquium held by The South African Institute of Mining and Metallurgy at Randburg in November 1988.

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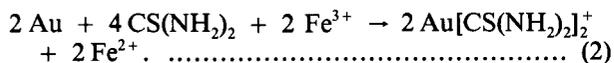
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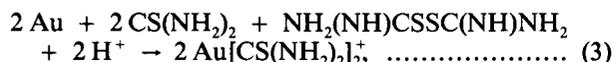
This reaction needs to take place in an alkaline medium to reduce the loss of cyanide in the form of hydrogen cyanide gas. The oxidant in this case is atmospheric oxygen, and the resulting aurocyanide complex is anionic.

*The Dissolution of Gold in Thiourea Solution*

In the presence of ferric ions, which are the most commonly used oxidant for the leaching of gold in thiourea solutions, the oxidation and complexing of gold can be represented by the following reaction<sup>4-6</sup>:



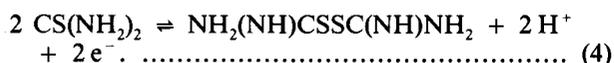
In the presence of hydrogen peroxide, the following reaction has been proposed<sup>4-6</sup>:



where CS(NH<sub>2</sub>)<sub>2</sub> is thiourea, NH<sub>2</sub>(NH)CSSC(NH)NH<sub>2</sub> is formamidine disulphide, and Au[CS(NH<sub>2</sub>)<sub>2</sub>]<sup>+</sup> is the cationic gold-thiourea complex.

The dissolution of gold by thiourea needs to take place in an acidic medium to prevent the rapid conversion of thiourea to urea [CO(NH<sub>2</sub>)<sub>2</sub>] and sulphate ions<sup>6</sup> in the presence of oxidants.

As shown in reaction (3), formamidine disulphide (FD) can act as an oxidant of gold in thiourea solutions. FD is formed *in situ* by the action of oxidants, such as hydrogen peroxide, on thiourea according to the following rapid reversible reaction<sup>4-6</sup>:



This reaction is followed by other slower, but irreversible, reactions that yield products containing sulphur with a higher oxidation state than S<sup>2-</sup>, for example by decomposition to cyanamide (H<sub>2</sub>NCN) and elemental sulphur, or to urea and sulphate ions. The rate and extent of these reactions depend on, among other factors, the pH value and the redox potential<sup>6,7</sup>.

*The Degradation of Thiourea*

For the oxidation of gold to occur, a redox potential higher than 150 mV, as measured between a platinum indicator electrode and a saturated calomel reference electrode (SCE), needs to be maintained<sup>4</sup>. In addition, as Schulze<sup>7</sup> and Nomvalo<sup>4</sup> have shown, higher redox potentials result in superior dissolution kinetics. However, at redox potentials greater than 250 mV, the irreversible oxidation of thiourea to secondary oxidation products, such as cyanamide and elemental sulphur, leads to the unacceptably rapid consumption of thiourea<sup>4,7</sup>. The formation of elemental sulphur in solution has a particularly detrimental effect on the dissolution of gold, since the mineral particles are passivated by an adhesive layer of fine sulphur<sup>4,7</sup>. Schulze<sup>7</sup> described a procedure in which the consumption of thiourea can be suppressed, at redox potentials as high as 400 mV (SCE), by the addition of

sulphur dioxide to the solution in the form of gas or as sodium metabisulphite powder<sup>4</sup>. However, efforts by Fleming and Fourie<sup>1</sup> and by Nomvalo<sup>4</sup> to reproduce the results obtained by that method were unsuccessful.

Groenewald<sup>6</sup> reported that iron(III) oxidizes thiourea to its secondary oxidation products less rapidly than other oxidants. (These oxidation products retard the dissolution rate of gold.) The slow rate of the redox reaction between iron(III) and thiourea is due to the formation of the stable complex [Fe(III) SO<sub>4</sub> CS(NH<sub>2</sub>)<sub>2</sub>]<sup>+</sup> in a sulphate medium. The end product of the reduction of iron(III) was identified as the complex [Fe(II)(CS(NH<sub>2</sub>)<sub>2</sub>)]SO<sub>4</sub>. Since the passivation of mineral particles is thus decreased by the use of iron(III) as an oxidant, the dissolution rate of gold by fresh acidic solutions of thiourea and iron(III) is higher than that obtained with other oxidants.

However, the complexing reaction between iron(III) and thiourea leads to a high consumption of reagents. The leaching solution also becomes less effective with time owing to various reactions between thiourea and iron(III)<sup>8</sup>. Furthermore, activated carbon catalyses the oxidation of thiourea in the presence of oxidants<sup>7,9</sup>. Unless air and other oxidants are removed from the solution prior to the adsorption step, the activated carbon could become poisoned by the deposition of elemental sulphur in the pores. This phenomenon would obviously also increase the consumption of thiourea. The high consumption of reagents is, in fact, one of the main obstacles to the more common use of thiourea as a lixiviant for gold and silver<sup>7</sup>.

**Selection and Preparation of the Site**

The underground leaching and adsorption equipment was installed at the end of a gully, from where access could be gained to two stopes, as shown in Fig. 1. In-stope leaching experiments could be conducted in both stopes without the equipment being moved. Stopes with small areas were chosen so that any losses of solution would be minimized and the rates of recovery per unit area could be monitored more accurately.

The leaching and recovery circuit (Fig. 1) consisted of five 500-litre polyethylene storage tanks, an upward-flow carbon column constructed of unplasticized polyvinyl chloride (UPVC), and two 25 mm Uniflow pumps. The leaching solution could be sprayed either through six evenly spaced 3/8-inch nozzles (type 930-BX polypropylene hollow-cone spray nozzles) that were fixed in a 6 m long hose, or via a hand-held hose fitted with a 1/2-inch UPVC Veejet spray nozzle. (The suitability of several nozzles was assessed by Priddle<sup>10</sup>.)

The first test was carried out in stope no. 1, which had previously been thoroughly swept. Planks were nailed to a row of roof supports across the bottom of the stope and were then sealed with cement, which was in turn painted with an acid-resisting epoxy paint, thus forming a retaining wall at the lower end of the region to be treated. A return-flow pipe was installed immediately in front of the wall, and led into the first storage tank. During the preliminary experiments, a ventilation duct connecting the ends of the two stopes was discovered, and was sealed off with cement to prevent the loss of leaching solution from stope no. 1. Fig. 2 shows a schematic view of the area (approximately 250 m<sup>2</sup>) that was treated.

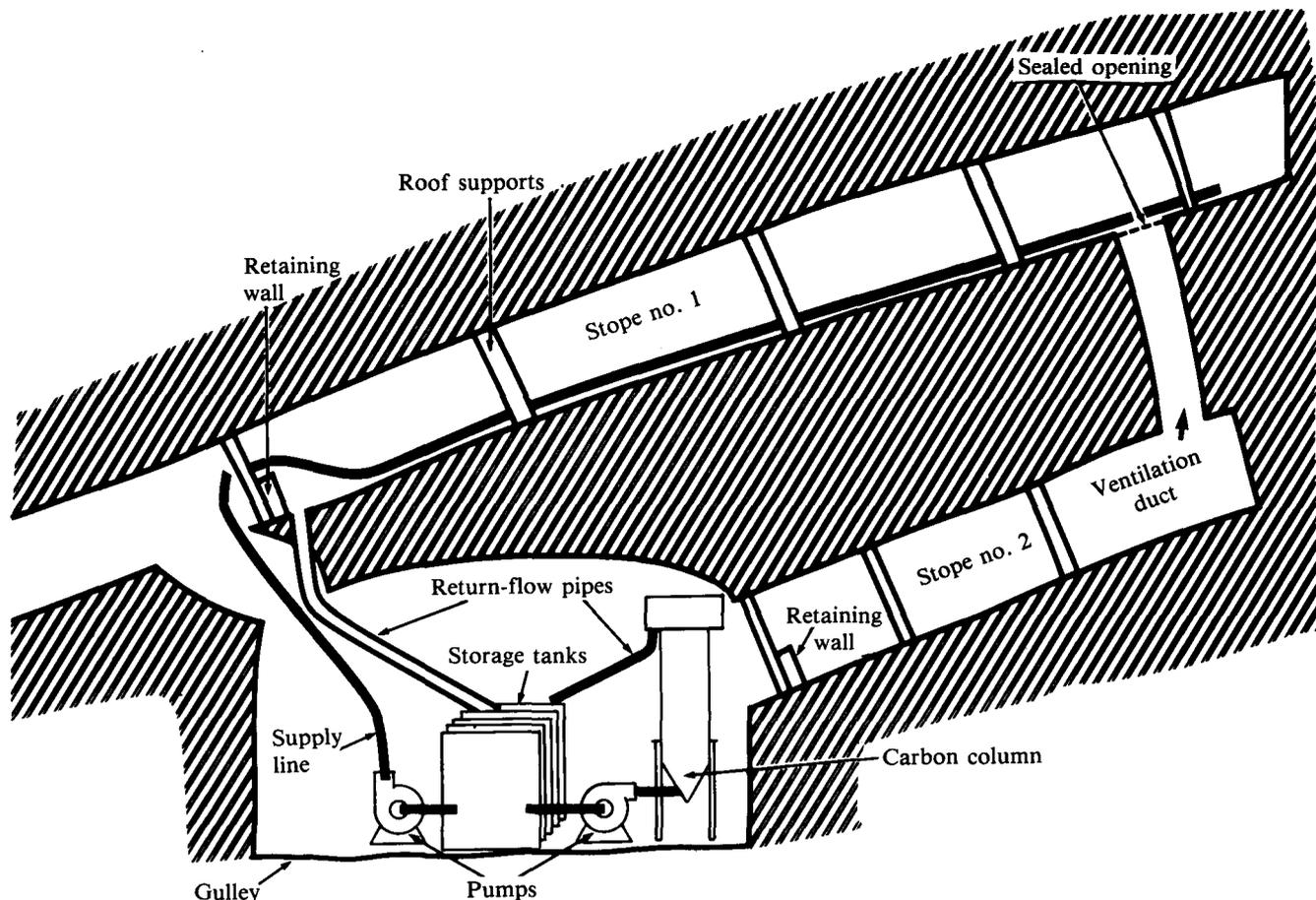


Fig. 1—Layout of the equipment for the in-stope leaching campaign

After the experiments in stope no. 1 had been completed, a retaining wall similar to that in stope no. 1 was built at the lower end of stope no. 2, as shown in Fig. 1. Fig. 3 shows that the greater part of stope no. 2 was inaccessible. The accessible part, which was about 150 m<sup>2</sup> in area, had not been swept and contained several tons of loose, mostly coarse material. In order to prevent an excessive amount of solid material from being washed into the storage tanks, an 850 μm polypropylene screen mounted on a wooden frame was placed over the inlet of the return-flow pipe.

#### Determination of the Rate of Leakage

Cracks or fissures can be present in the footwall of any stope as a result of mining activities and/or natural causes. Leaching solution containing dissolved gold and leaching reagents can therefore be lost by leakage into these cracks during in-stope leaching. It is therefore important that the rate of leakage should be measured prior to the commencement of leaching, and that preventive measures should be taken, if possible, when unacceptable leakage rates are encountered.

Before the in-stope leaching started, the five storage tanks were filled with water. This water was then circulated through stope no. 1 and flowed back into the storage tanks via the return-flow pipe. Coarse solid material that was washed into the storage tanks settled in tanks 1 and 2, thus preventing damage to the pumps or blockage of the spray nozzles. The volume of water in each tank was periodically measured with the aid of a calibrated dip-

stick.

Fig. 4 shows the results of a leakage test that was carried out after most of the leakage points had been sealed off with cement. It can be seen that, during the initial 125 minutes, the liquid inventory decreased rapidly as the pipes were filled and the stope was saturated with moisture. Eventually, the rate of liquid loss decreased and thereafter remained constant at 0,32 l/min (19 l/h), which represents the rate at which solution was lost by leakage. Visual inspection during leaching showed that the loss of liquid by mist drifting out of the stope was negligible. The leakage rate was regarded as acceptable, and no further effort was made to locate the remaining leaks. By extrapolation of the data in Fig. 4, the volume of solution needed to fill the pipes and saturate the stope was calculated to be 319 litres.

#### Leaching Tests in Stope No. 1

The pH value of the water in the storage tanks was adjusted to about 1,5 by the addition of 98 per cent sulphuric acid, and the solution was circulated through the stope for 5 hours. During this period, a redox potential of about 450 mV (SCE) was recorded. Thiourea was then added to the solution, and leaching started.

The leaching conditions were recorded hourly and were controlled within the following ranges:

Thiourea concentration	0,9 to 1,1 g/l
pH	1,5 to 2,0
Redox potential	160 to 200 mV (SCE)
Sulphuric acid concentration	2 to 5 g/l (approx.).

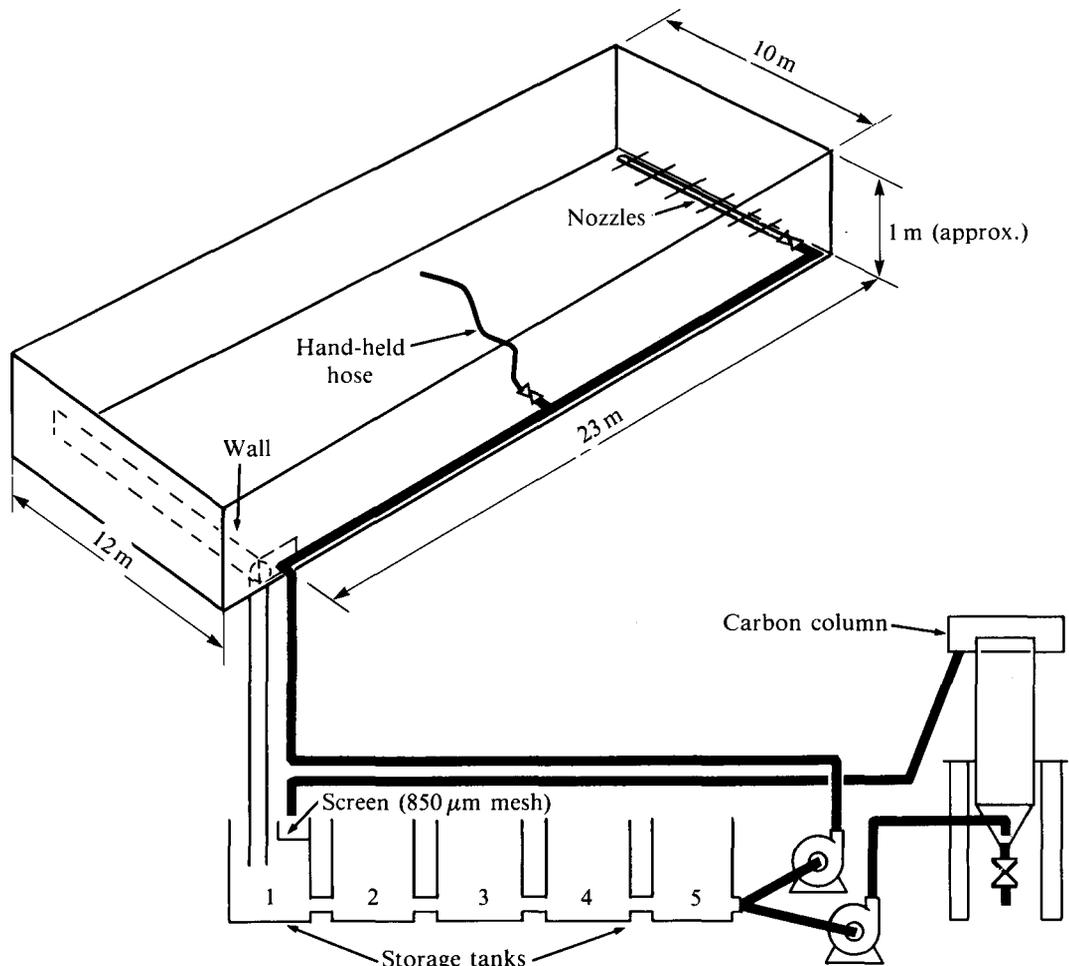


Fig. 2—Schematic view of stope no. 1 and the leaching equipment

The thiourea concentration was checked by titration with potassium iodate, using starch as the indicator. The pH value and redox potential were measured with the respective electrodes. The pH value was controlled by additions of 98 per cent sulphuric acid, and the redox potential by additions of ferric sulphate. During the first day of leaching, the redox potential remained between 150 and 200 mV, and the addition of oxidant was not necessary. The temperature of the leaching solution remained close to 22°C throughout the test.

The solution in each storage tank was sampled daily and analysed for gold. The volume of solution left in each tank was recorded whenever samples were taken, and the total amount of gold in solution was calculated.

In-stope leaching was carried out by the following operations. The leaching solution was pumped through the six fixed spray-nozzles in the 6 m hose, which was placed at the highest end of the stope and positioned at an angle that brought about wetting of the maximum area of the stope by droplets and drifting mist. A total flowrate of 43,5 l/min was measured. The whole area of the foot-wall, hangingwall, and sidewalls of the stope were sprayed with a hand-held hose. Spraying was carried out by a labourer who was equipped with a plastic coat, a head cover plus face mask, and plastic gloves. A flowrate of 37,5 l/min was measured. Finally, the solid material that had been washed from the stope into storage tank no. 1 was suspended by the circulation of solution from tank no. 5 into tank no. 1 at a flowrate of about 100 l/min.

The stope was not sprayed during this period.

The experiments in the first stope continued for two weeks. Leaching was carried out for a period of 5 hours each weekday, until the gold content of the solution reached about 1,5 to 2 mg/l. Leaching was then stopped, and most of the dissolved gold was recovered from solution by adsorption onto activated carbon. The adsorption step usually continued for about 5 hours.

#### The Recovery of Gold with Activated Carbon

A single 4 kg batch of granular activated carbon (Copcarb ANK 11) was used for the recovery of gold during the leaching of the first stope. Prior to leaching, the carbon was washed with water for one hour by fluidization of the bed to twice the settled bed height. In the adsorption step, the pregnant solution was pumped upwards through the column. The upward flow of solution in the column was between 2,2 and 2,6 cm/s, corresponding to a flowrate of between 55 and 65 l/min, which fluidized the carbon bed to 1,5 times its settled height.

The solution was circulated from tank no. 5 through the column and back into tank no. 1 via an 850 μm screen, which retained any particles of carbon that had been washed out of the column. The leaching solution in each tank was sampled before and after each adsorption step, and the amount of gold adsorbed onto the carbon was calculated from the cumulative difference between the total gold in solution prior to and after each adsorption cycle. These calculated results were checked against the

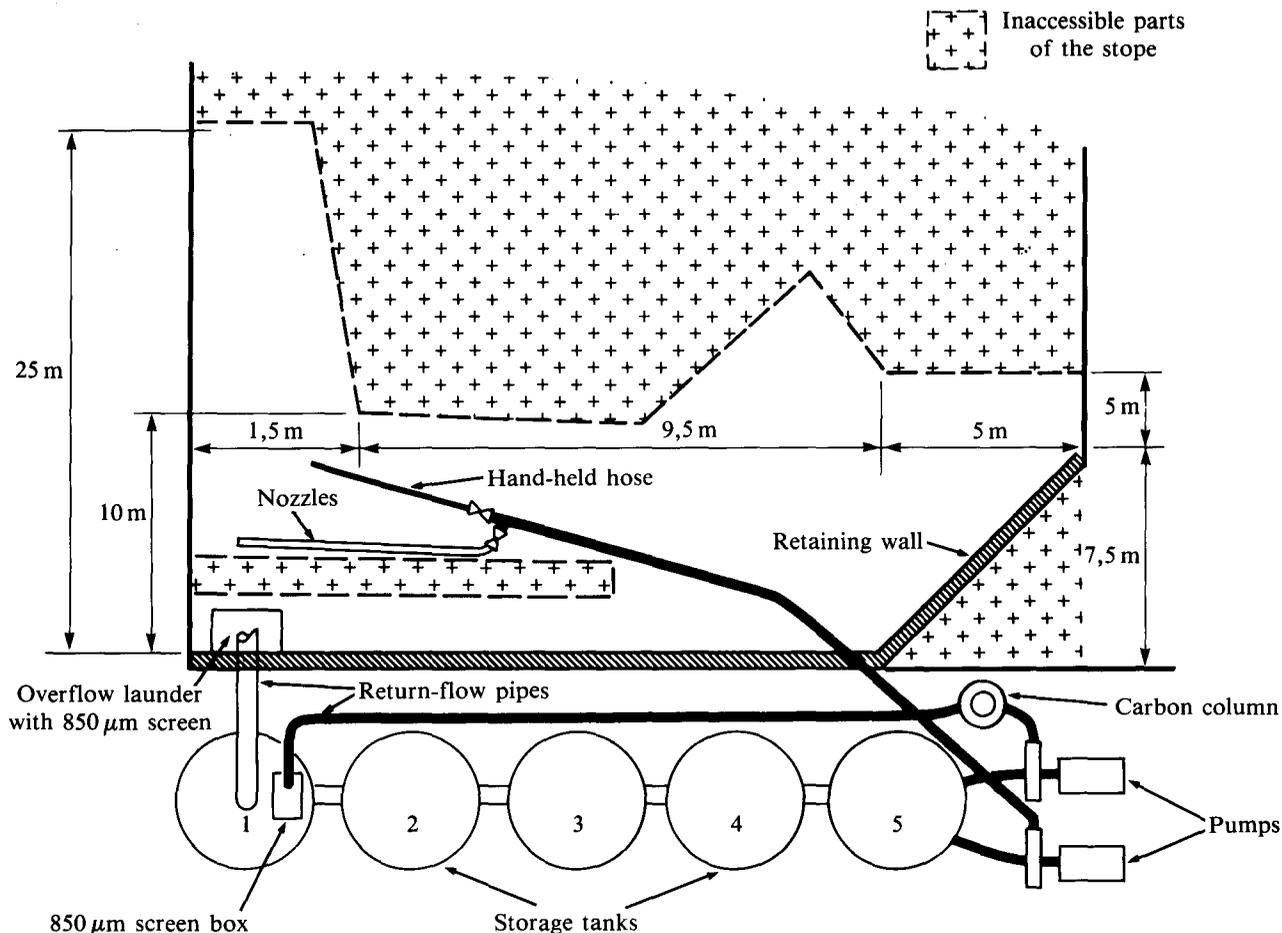
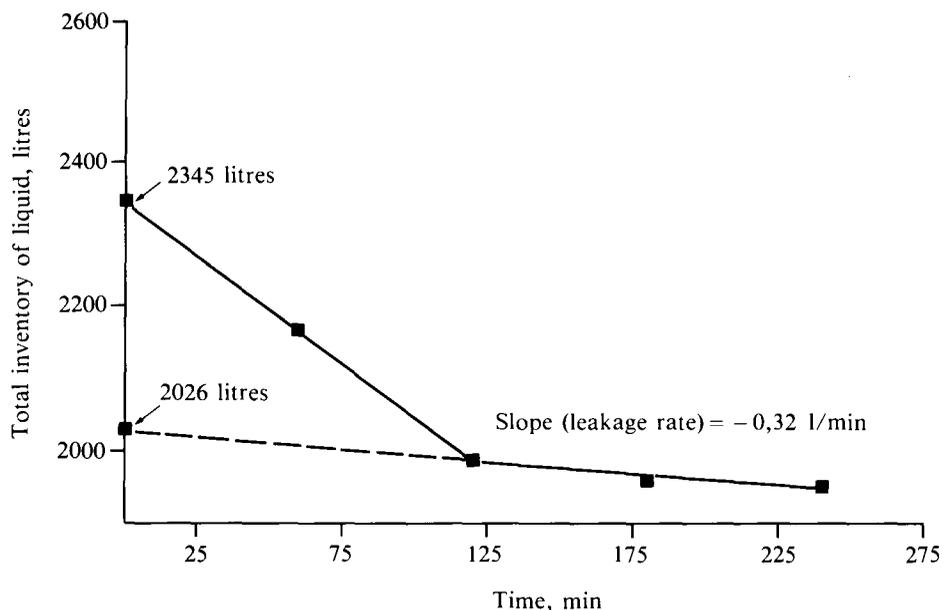


Fig. 3—Plan of stope no. 2 and the leaching equipment

Fig. 4—Determination of the leakage rate



actual carbon loadings, which were obtained periodically by assay.

#### Leaching Tests in Stope No. 2

Prior to the leaching tests in stope no. 2 the material on the stope was sampled. The samples were assayed for

gold, and were subjected to comparative leaching tests with thiourea and with cyanide in rolling bottles. The results of these tests are discussed in the following section of this paper.

The barren solution that remained after the leaching tests in stope no. 1 was used to determine the rate of

leakage from stope no. 2, thus avoiding the necessity of its disposal. The leakage rate was tested over a 5 hour period, and appeared to be zero. Immediately prior to the start of leaching in stope no. 2, the solution contained about 0,5 g/l of thiourea, 1 g/l of sulphuric acid, and 0,02 mg/l of gold.

The leaching conditions and method were the same as those used for the first stope, except that a higher redox potential—about 200 mV (SCE)—was used in an attempt to enhance the dissolution rate of the gold. After the stope had been sprayed for four days, a sample of the solid material that had been washed through the 850  $\mu\text{m}$  screen over the inlet of the return-flow pipe and accumulated in storage tank no. 1 was taken for leaching tests in rolling bottles.

A second 4 kg batch of fresh activated carbon was used for the recovery of gold from the second stope. However, this batch of carbon became virtually completely inactive after it had reached a gold loading of about 875 g/t. This batch of carbon was then replaced with a third batch of carbon, which was used until the tests in the second stope had been completed.

#### Discussion: Laboratory Investigation

Table I shows the size analysis and gold distribution for a sample of the material that was obtained from the surface of stope no. 2. (No sample could be obtained from stope no. 1 since it had previously been well swept.) The gold is concentrated in the finer fractions, with the highest gold content in the fraction between 106 and 850  $\mu\text{m}$ . The high concentration of gold in the finer fractions is confirmed by the high gold content (17 g/t, Tables II and III) of the material smaller than 850  $\mu\text{m}$  that was washed into the storage tanks.

TABLE I  
SIZE ANALYSIS AND GOLD DISTRIBUTION FOR SURFACE MATERIAL FROM STOPE NO. 2

Size	Mass %	Au	
		Assay g/t	Distribution %
> 19 mm	32,7	1,34	7,9
> 8 mm < 19 mm	23,3	2,56	10,9
> 850 $\mu\text{m}$ < 8 mm	24,9	3,26	14,8
> 106 $\mu\text{m}$ < 850 $\mu\text{m}$	13,4	23,5	57,3
< 106 $\mu\text{m}$	5,7	9,32	9,66
Overall (calc.)	100	5,5	100
< 19 mm (calc.)		7,6	

Tables II and III summarize the results of the rolling-bottle leaching tests on the sample of the surficial material from stope no. 2, and on the material that was washed into the storage tanks during leaching. It is clear that the dissolution obtained by cyanidation was much greater than that obtained by leaching with thiourea. Although the sample smaller than 850  $\mu\text{m}$  had been in contact with the lixiviant during the 4 days of in-stope leaching, it still contained a gold value of 17,1 g/t, and a further 18,1 per cent dissolution was obtained during the 24-hour rolling-bottle leaching with thiourea. This indicates that in-stope leaching is not very efficient.

TABLE II  
DISSOLUTION OF GOLD FROM SAMPLES OF MATERIAL FROM STOPE NO. 2 BY CYANIDATION FOR 24 HOURS IN ROLLING BOTTLES

Size fraction	Additions kg/t		Au			
	NaCN	Ca(OH) <sub>2</sub>	Head g/t	Residue g/t	Head (calc.)* g/t	Dissolution %
< 850 $\mu\text{m}$ † (test no. 1)	4	10	17,1	7,8	14	54,4
< 850 $\mu\text{m}$ (test no. 2)	4	10	17,1	6,8	11	60,2
< 850 $\mu\text{m}$ (av.)	4	10	17,1	7,3	12,5	57,3
< 19 mm‡	0,7	5	2,76	0,32	1,76	88,4

\* Calculated from the residue value and the gold in the pregnant solution

† Obtained from storage tank no. 1 after 4 days of leaching

‡ Obtained from stope no. 2 prior to leaching

The results for the material smaller than 19 mm are subject to greater error than those for the material smaller than 850  $\mu\text{m}$ , since it is difficult to obtain a small representative sample from such coarse material.

#### Discussion: Leaching of Stope no. 1

Fig. 5 shows the rates of gold dissolution during each stage of the leaching cycle. It can be seen that very little dissolution of gold took place when the solution was sprayed via the fixed spray-nozzles, since a very small area of the stope was being wetted by this form of spraying. However, manual spraying of the stope resulted in a dissolution rate of 0,023 g/h. When the mode of spraying was changed back to the fixed spray-nozzles, again virtually no dissolution took place. During the circulation of the solution from tank no. 5 to tank no. 1, the rate of dissolution was 0,03 g/h. This suggests that dissolution takes place at an appreciable rate only under turbulent conditions since, although the fine solid material had already settled in a stagnant bed at the bottom of tank no. 1 by the time the stope was sprayed with the fixed spray-nozzles for the second time, virtually no dissolution of gold from this material took place during that period.

After 364 hours (15 days), a total of 4,7 g of gold had been dissolved, 4,6 g of which was recovered by adsorption onto 4 kg of activated carbon.

#### Recovery of Gold

Fig. 6 shows the gold loading on the first batch of carbon as a function of the volume of solution circulated through the column. From the slope of the graph, it can be seen that the gold loading on the carbon increased by an average of 0,17 g/t with every 10 litres of solution that passed through the column.

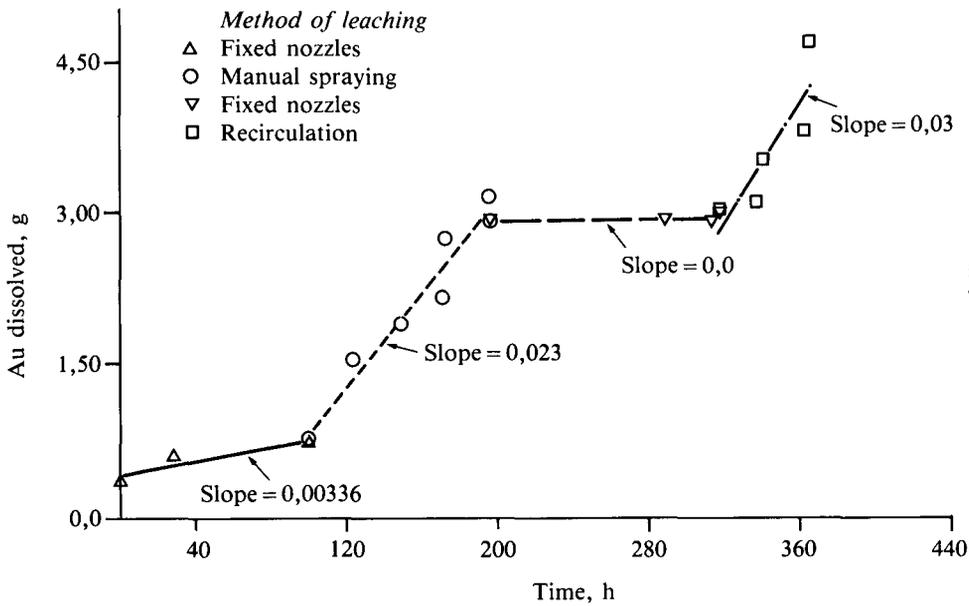
#### Consumption of Reagents

During the leaching of stope no. 1, 1760 litres of solution was lost due to leakage, and about 4 kg of thiourea, 20,6 kg of sulphuric acid (21 kg of 98 per cent H<sub>2</sub>SO<sub>4</sub>), and 562 g of ferric ions (4 kg of ferric sulphate) were consumed.

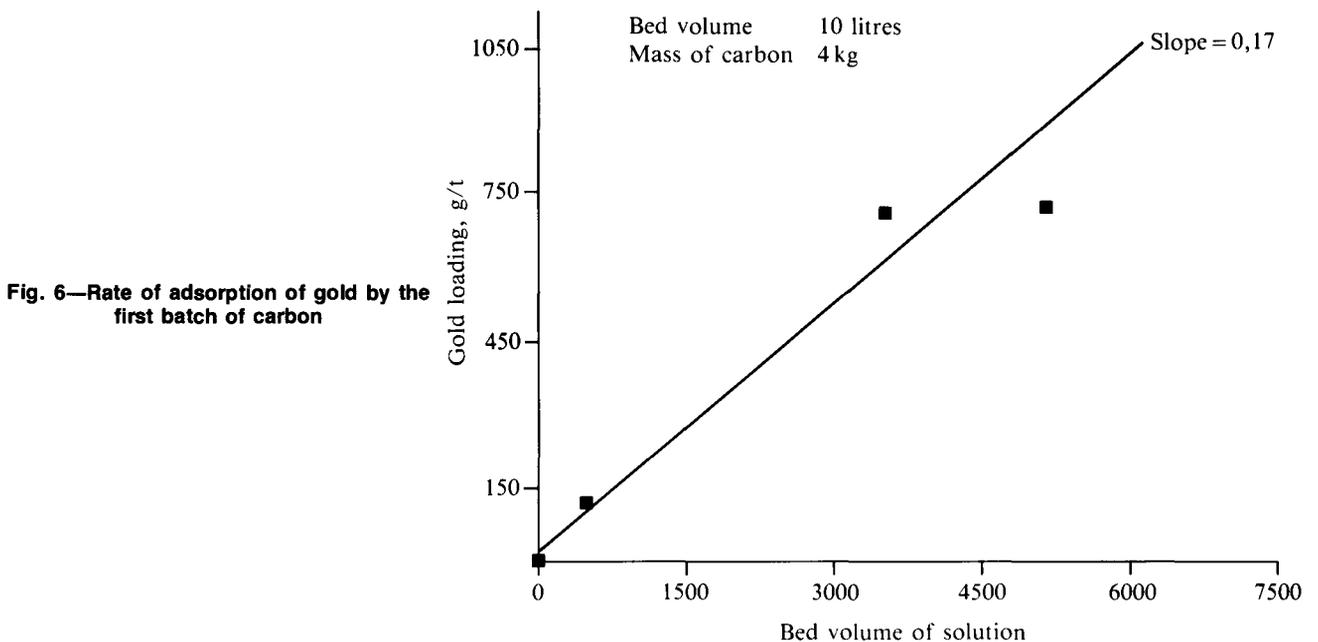
**TABLE III**  
**DISSOLUTION OF GOLD FROM SAMPLES OF MATERIAL FROM STOPE NO. 2 BY LEACHING WITH THIOUREA FOR 24 HOURS IN ROLLING BOTTLES**

Size fraction	Leaching conditions			Au			
	Thiourea g/l	E mV(SCE)	pH	Head g/t	Residue g/t	Head (calc.)* g/t	Dissolution %
< 850 $\mu\text{m}$ † (test no. 1)	1	200	1,5	17,1	14,0	16,0	18,1
< 850 $\mu\text{m}$ (test no. 2)	1	200	1,5	17,1	14,0	15,0	18,1
< 850 $\mu\text{m}$ (av.)	1	200	1,5	17,1	14,0	15,5	18,1
< 19 mm‡	1	210	1,4	2,76	0,38	2,1	23,9

\* Calculated from the residue value and the gold in the pregnant solution  
 † Obtained from storage tank no. 1 after 4 days of leaching  
 ‡ Obtained from stope no. 2 prior to leaching



**Fig. 5—Dissolution of gold during the leaching cycle in stope no. 1**



**Fig. 6—Rate of adsorption of gold by the first batch of carbon**

### Discussion: Leaching of Stope no. 2

During the leaching of stope no. 2, gold was dissolved effectively only when the stope was sprayed manually. Despite the use of a relatively high redox potential, the maximum rate of leaching (0,014 g/h) was about half that in the first stope (0,03 g/h). The low rate of dissolution observed may have resulted from the adsorption of gold-thiourea onto clay minerals in the loose material on the stope. This adsorbed gold would be liberated only by a wash with hot acid or thiourea<sup>7</sup>. After about 600 hours of leaching, a fine white precipitate appeared in solution, and the concentrations of various species in solution suggested that the leaching solution had become saturated with calcium sulphate.

After about 1000 hours (42 days) of leaching, a total amount of 6,5 g of gold had been dissolved from stope no. 2, of which 5,6 g was eventually recovered with activated carbon. Of the total amount of gold recovered, 3,5 g was adsorbed onto the second batch (4 kg) of carbon, and the remaining 2,1 g on the third batch of carbon.

### Recovery of Gold

The initial rate of adsorption of gold onto the second batch of carbon was 0,28 g/t per bed volume. When the loading of the carbon reached a value between 770 and 875 g/t, after 598 hours of adsorption, the rate of adsorption decreased dramatically. Since a higher gold loading (between 950 and 1150 g/t) had been obtained on the first batch of carbon, during the leaching of stope no. 1, the slow rate of adsorption could not have been due to the carbon approaching equilibrium gold loading. The carbon was therefore subjected to a standard activity test in a rolling-bottle, during which gold was adsorbed from a 20 g/t solution. After 1 hour, the gold content of the solution was 15 g/t, which confirmed that the carbon had become almost completely inactive.

A chemical analysis of the carbon indicated that the concentrations of most species were relatively low. However, an unusual amount of sulphur—10,4 per cent, 1,6 per cent of which was accounted for by the 4,8 per cent sulphate content—was present on the carbon. An unidentified dark-brown sludge with a strong smell, as well as 3,3 per cent by mass elemental sulphur, was extracted from the fouled carbon with methanol and tetrachloroethylene respectively<sup>11</sup>. Since no elemental sulphur could be detected in solution by gravimetric analysis, it was concluded that the carbon had been fouled by the oxidation products of thiourea, the oxidation of thiourea being catalysed by carbon in the presence of the ferric ions. The higher gold loading that was achieved on the first batch of carbon without fouling can be explained by the fact that a lower redox potential, necessitating lower additions of ferric ions, had been used during the leaching of the first stope.

The fouled carbon was replaced with a third batch of fresh carbon, and an adsorption rate of 0,1 g/t per bed volume was achieved during the remaining part of the campaign.

### Consumption of Reagents

Virtually no leakage of water occurred during the leaching of stope no. 2. About 12 kg of thiourea, 48 kg

of sulphuric acid (49 kg of 98 per cent sulphuric acid), and 3,7 kg of ferric ions (26 kg of ferric sulphate) were consumed. In order to maintain the higher redox potential, greater additions of ferric ions were necessary, which led to much greater consumptions of ferric ions and thiourea than during the leaching of stope no. 1. (A high redox potential could not be maintained by aeration of the solution.) The consumption of sulphuric acid per gram of gold leached was almost twice as much as that during the leaching of stope no. 1, probably because of the greater amount of acid-consuming oxides present in the loose material on the stope. The leaching of gold from stope no. 2 was therefore more costly than from stope no. 1.

### Conclusions and Recommendations

- (1) The leaching tests confirmed that some gold may remain in a worked-out stope even after it has been thoroughly swept.
- (2) From stope no. 1, a 'swept' stope with a footwall area of 250 m<sup>2</sup>, 4,7 g of gold was leached over a period of 15 working days, i.e. at a dissolution rate of 0,9 g per week per 100 m<sup>2</sup> of footwall area. From stope no. 2, which still contained broken rock, with an accessible footwall area of 150 m<sup>2</sup>, 6,5 g of gold was leached over a period of 42 working days. A dissolution rate of 0,7 g per week per 100 m<sup>2</sup> of footwall area was therefore achieved. However, the actual area available for solid-liquid contact in stope no. 2 was much greater than that available in stope no. 1 since stope no. 1 had been swept, whereas stope no. 2 was still littered with loose rock. The rate of gold dissolution in terms of grams per week per unit contact area from stope no. 1 was therefore much higher than that from stope no. 2.
- (3) The results of the testwork showed that the economic viability of in-stope leaching with thiourea solution is hampered by the following disadvantages.
  - (a) The loss of leaching solution from the stope by leakage may be unacceptably high. In-stope leaching experiments at more than one mine have failed owing to severe losses of solution.
  - (b) The dissolution rate of gold during in-stope leaching is slow, probably owing to poor contact and slow mass transfer between the lixiviant and the gold surfaces. This is attributed to the fact that, during in-stope leaching, the gold-bearing material is not turbulently suspended in the lixiviant but remains mostly static. The effective rate of dissolution may also be slowed down by the adsorption of gold-thiourea onto clay minerals in the stope material.
  - (c) Elemental sulphur, a product of the oxidation of thiourea, may passivate the mineral particles during leaching, and may also 'poison' the activated carbon during adsorption.
  - (d) Thiourea, which is an expensive reagent, oxidizes rapidly at redox potentials above 240 mV and in the presence of oxidants and activated carbon. Thiourea is also consumed by a complexing reaction with iron(III) and by adsorption onto clay minerals.

- (4) Even if in-stope leaching were economically viable, a reasonable profit would probably be realized only by a much larger-scale operation than that described in this paper. However, a larger-scale operation could suffer from the following problems.
- The larger-scale equipment required would involve greater capital costs, and hence greater financial risk.
  - The installation of the heavier and bulkier equipment would be time-consuming, owing to the limited space and lack of heavy lifting equipment underground.
  - The prediction of the performance of a larger-scale operation from the results obtained on a small scale is difficult, but the gold dissolution obtainable on a large scale is likely to be proportionately less efficient, rather than more efficient, than that obtained in a small-scale operation.
- (5) The results of the present investigation indicated that, in this case, the process of in-stope leaching with thiourea would not be economically attractive. However, leaching tests in a stope containing higher gold values could change this assessment.
- (6) The gold dissolution that can be achieved with cyanide solution appeared to be far superior to that obtained with thiourea solution. Although cyanide solutions could present a safety hazard during in-stope leaching, it is recommended that consideration should be given to a cyanide regime in future in-stope leaching experiments.

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#### References

- FLEMING, C.A., and FOURIE, A.J. Mintek, Randburg. Private communication, 1986.
- Statement on the question of the toxicity of thiourea. SWK Trostberg Aktiengesellschaft, Trostberg, 1984.
- CURTIS, M.W., and WARD, C.H. Aquatic toxicity of forty industrial chemicals. Testing in support of hazardous substance spill prevention regulation. *J. Hydrol.*, vol. 51. 1981. pp. 359-366.
- NOMVALO, Z.T. Thiourea leaching of Witwatersrand ore. *GOLD 100*. Fivaz, C.E., and King, R.P. (eds.). Johannesburg, The South African Institute of Mining and Metallurgy, 1986. vol. 2, pp. 565-577.
- HUYHUA, J.C., and GRUNDLER, I.H. Kinetics of leaching gold and silver in acidic thiourea solutions. *International Symposium on Hydrometallurgical Reactor Design and Kinetics*. Bautista, R.G., Wesley, R.J., and Warren, G.W. (eds.). Warrendale, The Metallurgical Society of AIME, 1986. pp. 247-264.
- GROENEWALD, T. Potential applications of thiourea in the processing of gold. *J. S. Afr. Inst. Min. Metall.*, vol. 77, no. 6. Jun. 1977. pp. 217-223.
- SCHULZE, R.G. New aspects of thiourea leaching of precious metals. *J. Met. (N.Y.)*, vol. 36. Jun. 1984. pp. 62-65.
- GROENEWALD, T. The dissolution of gold in acidic solutions of thiourea. *Hydrometall.*, vol. 1. 1976. pp. 277-290.
- FLEMING, C.A. The recovery of gold from thiourea leach liquors with activated carbon. 26th Annual Conference of Metallurgists, Canadian Institute of Metallurgy, Winnipeg. Apr. 1987.
- PRIDDLE, C.J. Johannesburg Consolidated Investment Company Limited, Johannesburg. Private communication, Sep. 1985.
- LEE, A.F. Mintek, Randburg. Private communication, 1987.

## Mining tax in the 1990s

Anglo American Corporation will shortly be presenting open seminars on mining tax in the 1990s. The subject is particularly topical, given the sweeping recommendations of the 1988 Marais Committee, and the enactment of substantial tax amendments in 1989. As the demand for this seminar is expected to be heavy, three seminars have been scheduled. The venue is the Central Training Unit, Vereeniging, and the dates 21st August, 13th September, and 17th October.

The duration of each seminar will be from 09:30 to 16:30 on those days. The cost of each seminar is R250 per person including lunch and comprehensive notes.

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