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MINES BRANCH INVESTIGATION REPORT IR 67-88

**FLOTATION INVESTIGATION ON A  
GOLD ORE FROM  
CAMPBELL RED LAKE MINES LIMITED  
BALMERTOWN, ONTARIO**

by

**G. I. MATHIEU AND R. W. BRUCE**

**MINERAL PROCESSING DIVISION**

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G. I. Mathieu\* and R. W. Bruce\*\*

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SUMMARY OF RESULTS

The ore sample contained 1.02 oz Au/ton and 1.54% S. In ore ground to -14 mesh, about 30% of the gold was free-milling and recoverable by jigging and amalgamation. The remainder occurred as fine grains of native metal, either free or as inclusions in arsenopyrite and, to some extent, in pyrite and pyrrhotite.

Flotation tests were done to determine the best conditions for maximum recovery of gold from the jig tailing in a concentrate containing about 17% sulphur (roasting grade). By successively finer grinding down to 97% -200 mesh, the gold content of the flotation tailing could not be reduced below 0.08 oz/ton, readily obtainable at 75 to 80% -200 mesh. In a locked-cycle test, simulating plant practice, flotation tailings assaying 0.08 to 0.09 oz Au/ton were consistently obtained, while producing concentrates with sulphur content of 16 to 17%. By comparison, gold assays of current mill tailings are reported to range from 0.10 - 0.125 oz/ton.

By longer flotation time and higher reagent concentration, somewhat lower-grade tailings were obtained, but at the expense of diluting the concentrate to less than 13% sulphur.

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## INTRODUCTION

Campbell Red Lake Mines is a gold producer located in Balmer township, Red Lake area, Northwestern Ontario. The company is currently milling 700 tons of ore per day.

Purpose of Investigation

Because of unduly high gold content in the mill tailing (0.10 to 0.125 oz/ton), Mr. E.A. Lago, Mill Superintendent, requested an investigation to determine the optimum fineness of grinding to obtain gold recovery by flotation, while producing a concentrate suitable for roasting (i.e. containing at least 17% sulphur). In addition, he expressed interest in the nature of the gold minerals in the flotation tailing and in their size-distribution.

Shipment

A 178-lb sample was received on February 17, 1967. The material was all -2 in. in size. Mr. Lago stated that the sample was representative of the rod mill feed over a period of six days.

Sampling and Analysis

A few representative pieces were selected from the ore for mineralogical examination. The remainder was crushed to -14 mesh from which a head sample was riffled out for chemical analysis.

TABLE 1

Chemical Analysis\* of Head Sample

Gold (Au)	-	1.02	oz/ton
Silver (Ag)	-	0.14	" "
Iron (Fe)	-	7.69	%
Sulphur (S)	-	1.54	"
Insoluble	-	52.15	"

\*From Internal Report MS-AC-67-394

A spectrographic analysis on a portion of the head sample indicated the following elements listed in their approximate order of decreasing abundance.

TABLE 2

Spectrographic analysis\* of Head Sample

I	-	Si, Fe, Mg, Ca
II	-	Al, Zn, Mn, Cr
III	-	Ti, Pb, Ni, Mo
IV	-	V, Zr, Co, Au, Ag

\*From Internal Report MS-AC-SL-67-34

MINERALOGICAL EXAMINATION\*

A few selected hand specimens and a portion of the head sample were sent to the Mineralogy Section of the Mineral Sciences Division to determine the main characteristics of the ore and the gold occurrence.

Procedure

Six polished sections and four thin sections were prepared from the hand specimens. In addition the -65+325 mesh sizes were screened from the head sample and separated into sink and float sub-fractions by means of heavy liquids. The float sub-fraction was run on the X-ray diffractometer to determine the principal gangue constituents, while two polished sections were prepared from the sink sub-fractions to determine the liberation of the gold and silver. The minerals in the ore were identified by microscopical and X-ray diffraction studies.

General Character of the Ore

The ore was found to be composed of highly metamorphosed gangue minerals containing disseminations of metallic minerals. The metallic minerals in the ore consist chiefly of arsenopyrite, pyrrhotite, pyrite, magnetite, chromite and berthierite, with lesser amounts of native gold, sphalerite, chalcopyrite, marcasite, ilmenite, stibnite, hematite and tetrahedrite. The gangue minerals are composed chiefly of dolomite and quartz, with lesser amounts of mica and chlorite, and traces of tourmaline. A small amount of an acicular gangue mineral in sheaf-like aggregates was also found, but could not be positively identified.

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\* From Internal Report MS-AC-67-59, by D. Owens.

### Detailed Mineralogy

Four grains of native gold were found in the examination of the polished sections of the hand specimens. One grain 5 microns in diameter was found in pyrite, while three grains 4, 12, and 22 microns in diameter were found in arsenopyrite. In addition, 11 grains of native gold were found in the head sample. Of these, 7 were free grains and varied in size from 12 to 105 microns, and the remainder, which varied in size from 4 to 26 microns were combined with other minerals. One of these was found enclosed in pyrite, one in pyrrhotite, one in arsenopyrite, and one between a combined grain of gangue and arsenopyrite. As well as the above mentioned occurrences, one grain of berthierite was found to be partially rimmed on two sides by a thin layer of native gold. No silver-bearing minerals were found.

The arsenopyrite occurs largely as euhedral grains disseminated in the gangue. They are generally quite small in size and vary from 10 to 150 microns in diameter. In a few instances small compact fine-grained masses of arsenopyrite grains were observed up to 600 microns in size. The arsenopyrite, like most of the metallic minerals in the ore, is generally free from inclusions, however, a few inclusions of pyrite, berthierite, and native gold were found in the arsenopyrite.

Pyrrhotite occurs in a manner similar to that of the arsenopyrite. The disseminations in gangue are irregular in shape and of a slightly coarser size and range from 5 microns up to one millimetre. Pyrrhotite is occasionally combined with grains of magnetite, and marcasite in gangue, and it is sometimes found as inclusions in magnetite. Inclusions in the pyrrhotite are few, and are composed of magnetite, arsenopyrite, chalcopyrite, and gangue which range in size from 10 to 30 microns.

The pyrite also occurs largely as irregular grains in gangue. These vary from 10 to 700 microns in diameter, and are generally free from inclusions. A few grains are intergrown with arsenopyrite, and contain a few small inclusions of magnetite, arsenopyrite and gangue. As previously mentioned one small grain of native gold was found in a grain of pyrite.

All of the chromite found in the ore occurs as cores in grains of magnetite. The magnetite, itself, is present as medium to fine-grained inclusions in gangue. The magnetite ranges from 10 to 300 microns in size, while the chromite cores vary from 5 to 200 microns in diameter. Not all of the magnetite grains contain chromite, and it is estimated that only about 30 per cent of the magnetite grains observed showed this feature. The magnetite was also found as combined grains with pyrrhotite in gangue, and occasionally contains inclusions of pyrrhotite.

Berthierite also occurs in the ore. It was found chiefly as fairly large grains in gangue, usually associated with stibnite.

These grains range from 5 microns up to 1.5 millimetres in diameter. A few grains were also found as inclusions in arsenopyrite, and the berthierite in turn, also contains a few inclusions of pyrite and arsenopyrite.

Only small amounts of sphalerite, chalcopyrite, marcasite, ilmenite, and stibnite were found in the ore. The sphalerite and ilmenite occur as individual grains in gangue. The sphalerite varies from 10 to 200 microns in size, while the ilmenite is slightly finer grained, and ranges from 5 to 25 microns in diameter. The only chalcopyrite found occurs as inclusions in pyrrhotite and gangue, and varies from 5 to 50 microns in size. Marcasite occurs as grains in gangue and as combined grains with pyrrhotite and pyrite in gangue. The amount is small and the size varies from 10 to 100 microns. As previously mentioned, the stibnite in the ore was found as combined grains with berthierite in gangue. These grains are few in number and range from about 20 to 350 microns in size.

While no hematite or tetrahedrite was found in the examination of the polished sections of the hand specimens, a few individual grains were found in the head sample.

### Conclusions

From the mineralogical examination of the ore, it can be concluded that the native gold occurs in more than one mineral, but predominates as inclusions in arsenopyrite. The number of free grains found in the head sample indicates that some of the gold appears to have been liberated during crushing.

### OUTLINE OF INVESTIGATION

In order to simulate plant practice, flotation of the ore was tested after the free-milling gold had been removed by jigging and amalgamation. Several flotation tests were made at increasing degrees of fineness to determine the optimum grinding conditions for gold recovery in a 17% sulphur concentrate. Production, in these tests, of intermediate products not separated in plant practice prompted a locked-cycle test to find their effect on the final tailing.

Size distribution analyses and leaching tests were done on the flotation tailing to determine the mode of occurrence of the residual gold. As gold was present associated with sulphide minerals, tests were conducted to recover these sulphides using longer flotation time and higher reagent concentration.



## DETAILS OF INVESTIGATION

Jigging and Amalgamation, Test 1

A 30,000-g sample of ore crushed to -20 mesh was fed to a laboratory jig and the concentrate produced was amalgamated for 2 hours with 20 ml of mercury.

TABLE 3

Results of Jigging and Amalgamation

Operation	Product	Weight %	Assays* oz/ton Au	Distribution % Au
Jigging	Concentrate	6.3	4.84	30.9
	Tailing	93.7	0.71	69.1
	Feed (calcd)	100.0	0.97	100.0
Amalgamation	Amalgam	-	4.09	84.5
	Residue	-	0.75	15.5
	Feed (calcd)	-	4.84	100.0
Jigging and amalgamation (overall recovery)				26.1

\* From Internal Report MS-AC-67-483.

Flotation of Jig Tailing, Tests 2-6

Five 2,000-g samples were split from the jig tailing, ground for 20, 30, 45, 60 and 90 minutes, and then floated using the procedure shown in Table 4.

TABLE 4

Reagents and Conditions of Flotation

Operation	Time min	Reagents	lb/ton	pH
Grinding		Xanthate Z-9 Aerofloat 25	0.25 0.02	
Conditioning	3	Copper sulphate	0.10	8.6
Rougher flotation	12	Dowfroth 250	0.04	8.5
Scavenger flotation	6	Xanthate Z-9 Copper sulphate Dowfroth 250	0.05 0.05 0.02	8.5
Cleaner flotation	6	Xanthate Z-9 Dowfroth 250	0.01 0.005	8.5
Re-cleaner flotation (twice)	4	Xanthate Z-9 Dowfroth 250	0.01 0.005	8.4

TABLE 5

Effect of Grinding on Flotation of Jig Tailing

Test	Product	Weight %	Assays* oz/ton Au	Distribution % Au
2 (64.5% -200m)	Recl conc	3.3	16.04	75.8
	Recl tailing	1.2	1.30	2.3
	Cl tailing	4.8	0.70	4.8
	Scav conc	2.9	0.80	3.3
	Flot tailing	87.8	0.11	13.8
	Feed (calcd)	100.0	0.70	100.0
3 (75.7% -200m)	Recl conc	3.0	18.35	78.5
	Recl tailing	1.1	1.34	2.1
	Cl tailing	4.3	0.65	3.9
	Scav conc	3.1	0.98	4.3
	Flot tailing	88.5	0.09	11.2
	Feed (calcd)	100.0	0.71	100.0
4 (86.0% -200m)	Recl conc	2.9	19.22	79.8
	Recl tailing	0.9	1.52	2.0
	Cl tailing	4.0	0.80	4.6
	Scav conc	3.4	0.70	3.4
	Flot tailing	88.8	0.08	10.2
	Feed (calcd)	100.0	0.70	100.0
5 (90.7% -200m)	Recl conc	3.4	16.36	77.8
	Recl tailing	1.2	0.78	1.4
	Cl tailing	4.0	0.38	2.3
	Scav conc	4.0	1.25	7.7
	Flot tailing	87.4	0.08	10.8
	Feed (calcd)	100.0	0.70	100.0
6 (97.7% -200m)	Recl conc	3.3	16.25	78.8
	Recl tailing	1.2	0.60	1.1
	Cl tailing	3.0	0.22	1.0
	Scav conc	4.3	1.38	8.7
	Flot tailing	88.2	0.08	10.4
	Feed (calcd)	100.0	0.68	100.0

\* From Internal Reports MS-AC-67-483 and 524.

Note: The sulphur content in the recleaner concentrates of each test was 17.9%, 18.8%, 19.5%, 17.4% and 17.1%, respectively.

Flotation of Combined Tailing from Jigging and Amalgamation,  
Tests 7 - 10

This series of tests was made on a sample composed of jig tailing and amalgamation tailing mixed in correct proportion. Each test used a 2,000-g sample and followed the procedure of Table 4, with the exception of Test 10. In this case, five cleaning stages were done in an attempt to increase the sulphur content of the final concentrate. The variable in the tests was the grinding period (20, 30, 45 and 37 minutes in tests 7, 8, 9 and 10, respectively). The results obtained are shown in Table 6.

TABLE 6

Effect of Grinding on Flotation of Jig and Amalgamation Tailings

Test	Product	Weight %	Assays* oz/ton Au	Distribution % Au
7 (76.1% -200m)	Recl conc	4.4	13.56	84.0
	Recl tailing	1.8	0.41	1.0
	Cl tailing	5.2	0.33	2.4
	Scav conc	4.4	0.50	3.1
	Flot tailing	84.2	0.08	9.5
	Feed (calcd)	100.0	0.71	100.0
8 (81.2% -200m)	Recl conc	4.9	12.22	84.0
	Recl tailing	1.7	0.47	1.1
	Cl tailing	6.5	0.27	2.5
	Scav conc	7.1	0.24	2.4
	Flot tailing	79.8	0.09	10.0
	Feed (calcd)	100.0	0.71	100.0
9 (85.9% -200m)	Recl conc	4.7	13.69	85.4
	Recl tailing	1.7	0.51	1.2
	Cl tailing	7.6	0.22	2.2
	Scav conc	4.3	0.26	1.5
	Flot tailing	81.7	0.09	9.7
	Feed (calcd)	100.0	0.75	100.0
10 (81.2% -200m)	Concentrate	3.7	15.44	83.1
	Middling**	15.4	0.28	6.3
	Flot tailing	80.9	0.09	10.6
	Feed (calcd)	100.0	0.72	100.0

\* From Internal Reports MS-AC-540, 604 and 643.

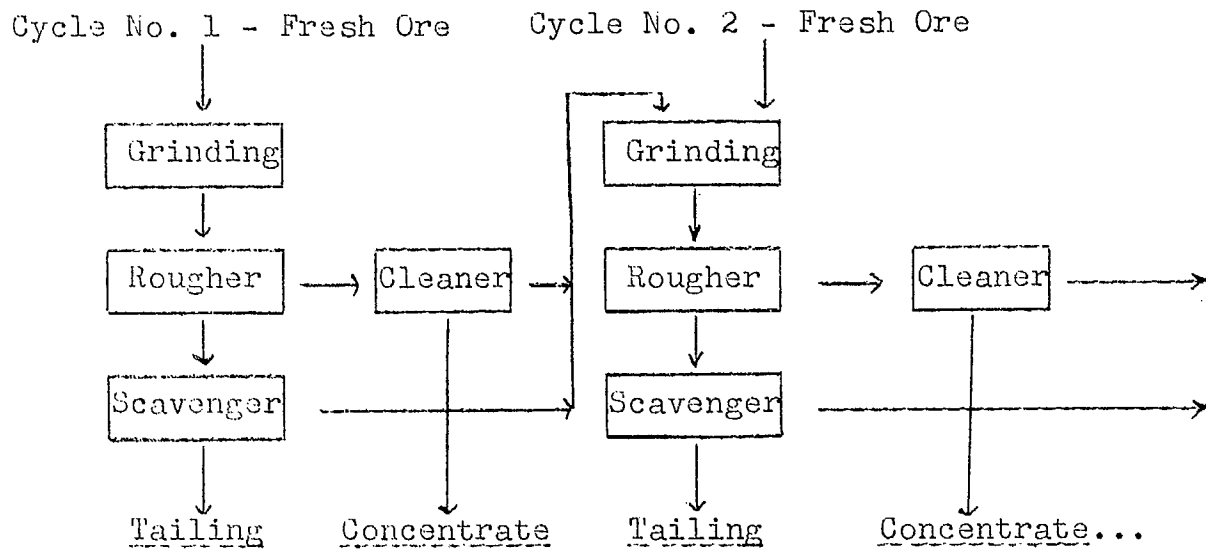
\*\* Including tailings from the five cleaning stages plus scavenger concentrate.

Note: The sulphur content in the concentrates of each test was 14.0%, 12.8%, 13.8% and 18.8%, respectively.

A few additional tests were made in which xanthate Z-11 was replaced by xanthate Z-6 and the concentration of copper sulphate was increased, but no significant improvement in the gold recovery was achieved by these modifications.

#### Integration of Five Cycles of Flotation, Test 11

This test was also carried out on combined tailing from jigging and amalgamation. It consisted of five identical cycles, in which the intermediate products of the previous cycle were added to a new ore sample (2000 g) prior to grinding and flotation. The scheme of the process is illustrated below:



In each cycle, the grinding time was 40 minutes and the flotation conditions were identical to those shown in Table 4, except that six stages of cleaning were necessary to attain the desired grade as shown in the following table of results.

TABLE 7

Results with Cyclical Flotation

Cycle No.	Product	Weight %	Analysis*		Distribution	
			oz/t	%	%	
			Au	S	Au	S
1 (81.9% -200m)	Concentrate	4.7	15.48	19.96	89.5	58.1
	Flot tailing	95.3	0.09	0.71	10.5	41.9
	Total (calcd)	100.0	0.81	1.61	100.0	100.0
2 (84.0% -200m)	Concentrate	4.4	13.94	17.05	88.9	57.5
	Flot tailing	95.6	0.08	0.58	11.1	42.5
	Total (calcd)	100.0	0.69	1.31	100.0	100.0
3 (84.8% -200m)	Concentrate	4.8	12.90	16.54	87.8	56.6
	Flot tailing	95.2	0.09	0.64	12.2	43.4
	Total (calcd)	100.0	0.70	1.40	100.0	100.0
4 (85.1% -200m)	Concentrate	4.7	13.18	16.04	89.0	56.7
	Flot tailing	95.3	0.08	0.62	11.0	43.3
	Total (calcd)	100.0	0.70	1.36	100.0	100.0
5 (85.6% -200m)	Concentrate	4.6	13.11	16.60	87.5	53.6
	Flot tailing	95.4	0.09	0.67	12.5	46.4
	Total (calcd)	100.0	0.69	1.41	100.0	100.0
1 - 5 (84.3% -200m)	Concentrates	4.4	13.71	17.27	85.5	53.4
	Middling**	3.5	0.56	2.09	2.8	5.2
	Flot tailings	92.1	0.09	0.64	11.7	41.4
	Feed (calcd)	100.0	0.71	1.42	100.0	100.0

\* From Internal Report MS-AC-67-643.

\*\* Including cleaner tailings and scavenger concentrate of cycle No. 5.

Although the gold content of the intermediate products increased from 0.28 oz/ton (see Test 10) to 0.56 oz/ton, the small weight per cent of these and the consistent assays of the flotation tailings (0.08 to 0.09 oz per ton) indicates that it should be possible to produce this tailing in plant practice, without appreciably reducing the sulphur grade of the concentrate.

However, since this represents a gold loss of at least \$3.15/ton of ore treated, efforts were made to determine the cause of the low recovery. Mineralogical examination gave no indication, because of the fineness of the tailing and the rare occurrence of gold particles. Therefore, leaching tests were made on selected size-fractions of the flotation tailing.

Screen and Infralyzer Analysis of Flotation Tailings, Test 12

A 500-g sample was made from representative portions of the five tailings from Test 11, and sized using a 200-mesh sieve and an infralyzer apparatus.

TABLE 8

Gold Content in Sized Fractions

Size microns	Weight %	Assays* oz/ton Au	Distribution % Au
+74 (200 mesh)	15.4	0.10	18.0
-74 + 40	11.1	0.08	10.3
-40 + 28	11.9	0.07	9.7
-28 + 20	14.7	0.05	8.5
-20 + 14	12.7	0.04	5.9
-14 + 10	10.1	0.07	8.2
-10	24.1	0.14	39.4
Feed (calcd)	100.0	0.09	100.0

\*From Internal Report MS-AC-67-111.

Leaching of Flotation Tailings, Test 13

After screening the flotation tailings from Test 11 on a 400-mesh screen, a 1000-g sample was cut from each fraction and cyanided for 30 hrs in a solution maintained at 1.0 lb NaCN/ton and 0.5 lb CaO/ton. A portion of each cyanidation residue was analysed and the remainder was treated in a 5% HCl solution until all the carbonates were dissolved. The acid residues were washed thoroughly, dried, weighed and then cyanided for another 24-hr at the above concentration of lime and cyanide. After cutting a sample for analysis, the cyanidation tailings were treated in hot aqua regia, and then assayed again. The test results and the corresponding gold distribution in the various components of the flotation tailings are shown in Tables 9 and 10.

TABLE 9  
Results of Leaching

Size	Product	Weight %	Analysis*		Distribution	
			oz/ton Au	% S	% Au	% S
+400 mesh	Flot tailing	100.0	0.10	0.33	100.0	100.0
	1st cy residue	100.0	0.030	0.33	30.0	100.0
	2nd cy residue	75.2	0.030	0.44	22.6	100.0
	Aqua regia residue	68.7	0.003	0.02	2.1	6.1
-400 mesh	Flot tailing	100.0	0.08	0.67	100.0	100.0
	1st cy residue	100.0	0.040	0.68	50.0	100.0
	2nd cy residue	71.4	0.035	0.95	31.2	99.7
	Aqua regia residue	57.8	0.005	0.02	3.6	1.7

\* From Internal Reports MS-AC-938 and 945.

TABLE 10  
Gold Occurrence in Flotation Tailing

Gold-bearing Components	+400 mesh (26% by weight)	-400 mesh (74% by weight)
Exposed gold (cyanide-soluble)	70.0%	50.0%
Enclosed in carbonates	7.4%	18.8%
Enclosed in sulphides	20.5%	27.6%
Enclosed in insoluble gangue	2.1%	3.6%

Although the exposed gold and the gold-bearing sulphides might not be entirely free, the above results suggested that at least a portion of the gold contained in the flotation tailing should be recoverable by flotation. To confirm this, flotation tests were made in which both the reagent concentration and the flotation time were increased considerably.

Longer Flotation and Higher Reagent Concentration, Test 14

In this test, the ore was ground to 82% -200 mesh and floated using the procedure of Table 4, except that flotation time and reagent concentration were both increased by 50% throughout all the flotation stages including the six cleaning stages.



TABLE 11

Results with Longer Flotation and Higher Reagent Concentration

Product	Weight %	Analysis*		Distribution	
		oz/ton Au	% S	%	
				Au	S
Concentrate	5.7	10.56	12.73	86.6	54.9
Middling	20.0	0.23	1.62	8.1	24.1
Flot tailing	74.3	0.05	0.33	5.3	21.0
Feed (calcd)	100.0	0.70	1.34	100.0	100.0

\* From Internal Report MS-AC-66-604.

The final concentrate contained only 12.7% sulphur even after six stages of cleaning. This was due to heavy froth produced by the excess of frother and collector in both rougher and cleaner flotation. This reagent accumulation made it practically impossible to reject further gangue in the later cleaning stages. In a similar test, after ten stages of cleaning with reduced addition of reagents, no significant improvement in the final sulphur content was achieved. Since cleaning operation in plant practice would not likely be more effective if an intensive rougher flotation is used, it is doubtful that the gold content of the mill tailing can be reduced to 0.05 oz/ton without sacrificing the sulphur content of the final concentrate.

#### SUMMARY AND CONCLUSIONS

The gold assay of the ore sample received from Campbell Red Lake Mines Limited was 1.02 oz/ton and the sulphur content was 1.54%. Mineralogical examination of the ore and the results of the testwork indicated that the gold was distributed approximately as follows:

- (a) 60% occurred as native gold as grains ranging from 12 to 105 microns in size;
- (b) 40% was present as inclusions in arsenopyrite, pyrite and pyrrhotite.

Jigging of the ore ground to -20 mesh recovered 31% of the gold, thus showing that only the coarser free-milling gold was recoverable by this gravity concentration process. The jig concentrate was amalgamated.

Flotation of the jig tailing was then investigated to find if the gold content in the final tailing could be reduced below that obtained in plant practice (0.10 to 0.125 oz Au/ton), while maintaining the sulphur content of the final concentrate at 17% sulphur. A first series of tests on ore ground successively finer gave the following results:

<u>Fineness</u> (% -200m)	<u>Sulphur in Concentrate</u> (%)	<u>Gold in Tailing</u> (oz/ton)
64 - 75	16.0 - 18.8	0.11 - 0.09
76 - 90	17.4 - 19.5	0.09 - 0.08
91 - 98	17.1 - 17.4	0.08

A locked-cycle test on ore ground to about 84% -200m gave practically identical results. The consistent production of cycle tailings containing no more than 0.09 oz Au/ton indicates that similar results should be obtainable in plant practice giving a 3 to 5% increase in gold recovery, while maintaining the sulphur content in the concentrate at a satisfactory level.

Since a tailing of 0.09 oz/ton represents a gold loss of at least \$3.15 per ton of ore treated, attempts were made to find the cause of the rather ineffective flotation. Mineralogical examination failed to give any indication due to the fineness of the flotation tailing. However, a screen and infrasizer analysis showed that gold concentration was fairly uniform throughout all the sized fraction, while successive acid and cyanide leaching tests indicated that about 80% of the gold contained in the flotation tailing was either exposed (55%) or enclosed in sulphide minerals (25%).

Because the degree of gold liberation could not be inferred from this mode of investigation, intensive flotation tests were made to determine to what extent the gold content of the tailing could be reduced. In a few of these tests, done with flotation time and reagent concentration increased by 50%, the final tailings were 0.05 oz Au/ton. However, the resulting concentrates even after multiple cleaning (up to ten stages) did not contain more than 13% sulphur. Since no better sulphur concentration is likely to be achieved in plant practice if intensive flotation is used, this procedure does not appear practical and the lowest tailing compatible with a 17% sulphur concentrate is probably about 0.09 oz/ton.

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