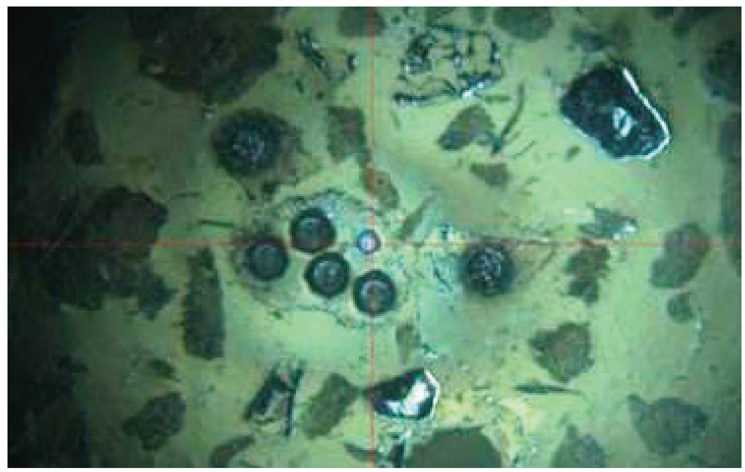

Bureau Veritas Minerals

Applications of Process Mineralogy in the Gold Deportment Study of Flotation Process Streams

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COM 2017 | The Conference of Metallurgists | www.metsoc.org
Published by the Canadian Institute of Mining, Metallurgy and Petroleum

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# ABSTRACT

The mineralogical characteristics of the process streams provide key indicators to the potential improvement in the metallurgical performance. Therefore, the process mineralogy and diagnostic metallurgy have been widely used as a tool to assist the metallurgists at the operating plants. The challenge of this study was then how to characterize the diagnostic flowsheet of the minerals of interest in the process streams across the flotation circuit. The investigation from this study indicates that the mineral schematic flowsheet can visibly demonstrate the sources that caused the gold losses during the mineral processing.

In this paper, we present studies of the flotation process stream samples, representing the feeds, intermediate products, final concentrate and final tails, which were produced from the flotation concentrators of Mt Carlton mine in Queensland, Australia. This study was focused on characterizing the process streams and learns how the gold in the process streams was associated with other sulphide minerals and host minerals on a size by size basis. The automatic QEMSCAN/MLA Particle Mineral Analysis (PMA) and Trace Mineral Search (TMS) were applied to identify the minerals and to detect the gold in the sized fractions of process streams. The Laser Ablation ICP-MS (LA) spot analysis, QEMSCAN EDS spot analysis and electron microprobe spot analysis were employed to identify and quantify the refractory gold concentrations in the sulphide minerals, like pyrite, and the elemental concentrations of visible gold grains. The diagnostic flowsheet of gold recoveries by the process streams, by mineral association classes and by the particle sizes were generated and discussed.

KEYWORDS

#Processmineralogy, #liberationandassociations, #golddeportment, #diagnostic, #flowsheet, #processstreams, #recoveriesbyclassbysize.

INTRODUCTION

The process mineralogy is world widely used to characterize the mineral composition and fragmentation characteristics of the ore feeds and process products, which are generated from the metallurgical tests or operating plants. The reason for this is that the mineralogical characteristics of process streams can directly assist the metallurgists to determine what improvement can be achieved in the metallurgical performances.

The flotation concentrators of Mt Carlton mine produce a polymetallic final concentrate, containing copper, gold and silver. This presentation mostly focus on discussions of gold deportment mineralogy of the flotation process streams: The questions to be addressed are: Is current primary grind sufficient for this ore type and does it give adequate mineral liberation? Does the regrinding circuit provide adequate improvement of copper sulphides and gold liberations? What are the sources of the diluents which reduce the grade of the final concentrate and what is the potential for improvement in the final concentrate quality? What are the sources of the copper and gold losses during the process of this ore type in the rougher and cleaner stages?

Based on the metallurgical balances during the period that these samples were taken, the copper and gold recoveries by the flotation streams and by association classes were estimated. The diagnostic flowsheet and metallurgical-mineralogical balances of rougher circuit and regrinding circuit are presented. The gold recoveries by size and by association class of the rougher circuit were also calculated. Due to the lack of a cleaner tail sample the mineralogical balances of the complete flotation circuit could not be determined.

METHODOLOGY

The mineralogical assessments were conducted on one set of twelve process stream samples, which were taken from the flotation concentrators of Mt. Carlton gold mine in Queensland of Australia. The representative cuts of each of the provided samples were taken for chemical and mineralogical studies. The wet screen and a cyclone sizer were conducted on each of the unsized process stream samples. The sized samples were grouped into five fractions for mineralogical studies.

Following the sample preparations, both QEMSCAN Particle Mineral Analysis (PMA) and Trace Mineral Search (TMS) for gold and silver were conducted on each fraction of the sized samples. The SIP (Specific Identification Protocols) was particularly developed for this set of Mt Carlton samples, to identify and quantify the mineralogical characteristics of the process stream samples. The quantitative X-Ray Diffraction (XRD) and Whole Rock Analysis (WRA) were also performed on the feed stream, to assist the QEMSCAN calibration for non-sulphide minerals. The Laser Ablation ICP-MS (LA) spot analysis, QEMSCAN EDS spot analysis and electron microprobe spot analysis was employed to identify and quantify the concentrations of refractory gold in the sulphide minerals, the elemental concentrations of gold grains and the elemental concentrations of sphalerite and enargite.

Feed Characteristics

The flotation feed contained elevated gold, silver and copper; assaying 3.1g/t gold, 13.7g/t silver and 0.16% copper. The mineral compositions and elemental deportments for gold, and copper of the flotation feed are shown in Figure 1.

Mineral Composition

Sulphide Minerals	Mass %	Non-Sulphide Minerals	Mass %
Silver Minerals	0.03	Iron Oxides	0.4
Chalcopyrite	0.01	Ilmenite	0.2
Bornite	0.02	Quartz	66.3
Chalcocite/Covellite	0.07	Dickite/Kaolinite	16.6
Enargite/Tennantite	0.20	Alunite	6.4
Wittichenite/Mawsonite	<0.01	Feldspars	1.2
Goldfieldite/Tetrahedrite	0.02	Muscovite	0.9
Galena	0.09	Chlorite	0.6
Sphalerite	0.24	Anatase	0.5
Pyrite	5.59	Calcite	0.2
		Others	0.4
Total	6.27	Total	93.7

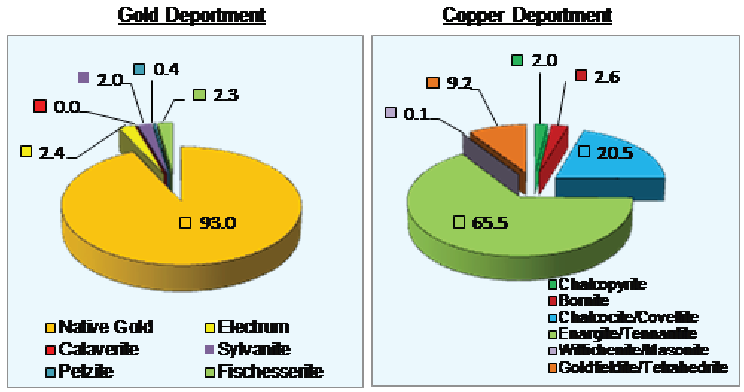


Figure 1. The mineral composition and elemental deportment by mineral species

At the primary grind size of 144 μm P80, the two dimensional liberations of gold and copper were measured at 68.7% and 53.9%, respectively (Figure 2A). The gold locking characteristics was particularly measured and displayed in Figure 2B. The effect of primary grind on the mineral liberations is shown in Figure 2C.

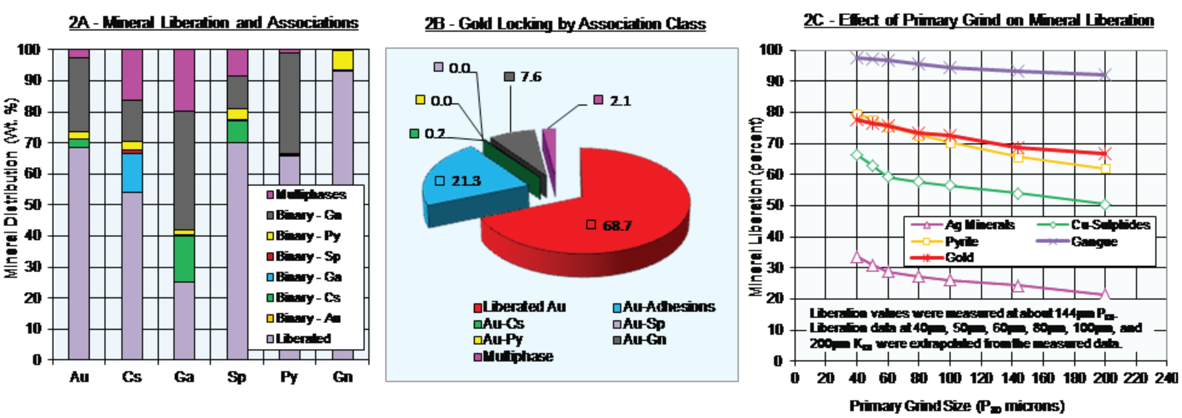


Figure 2. Evaluation of the efficiency of primary grinding

The quality of the copper and gold bearing particles are shown in Figure 3A and 3B. The limiting grade recovery curves (See Figure 3C) suggest that a rougher concentrate, assaying 5 to 10 percent copper at the around 90 percent copper recovery, can be theoretically achieved. Any further improvement in the copper concentrate grade will require finer grinding.

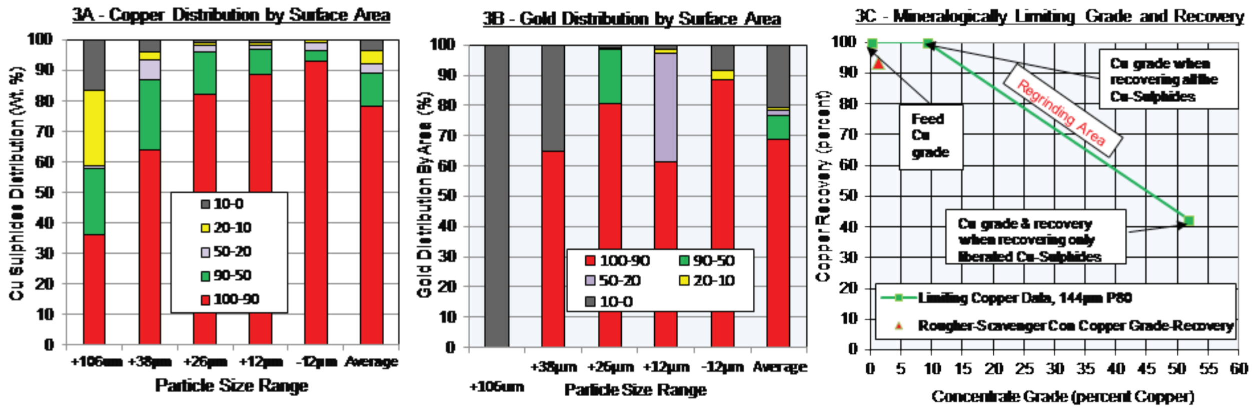


Figure 3. The anticipated gold-copper rougher flotation performance

Metallurgical and Mineralogical Performances

The elemental compositions and recoveries of sulphide flotation circuit are presented in Table 1.

Process Stream	Mass percent	Assays - percent or g/t								Distibution - percent							
		Cu	Pb	Zn	Fe	S	As	Ag	Au	Cu	Pb	Zn	Fe	S	As	Ag	Au
Flotation Feed	100	0.20	0.10	0.20	3.19	4.13	0.05	29	3.10	100	100	100	100	100	100	100	100
Final Concentrate	6.4	**2.83**	0.71	2.43	30.1	37.3	0.69	**160**	**41.8**	**89.9**	44.5	76.7	59.8	57.4	82.5	**35.5**	**85.5**
Final Tailings	93.7	0.02	0.06	0.05	1.37	1.88	0.01	20	0.48	10.1	55.5	23.3	40.2	42.6	17.5	64.5	14.5

Table 1. Overall metallurgical balance

Rougher – Scavenger Circuit Performance

The mineral response by streams and by particle sizes of the rougher-scavenger circuit was calculated based on the metallurgical balances and QEMSCAN analysis data. This data is displayed in Figure 4 and 5.

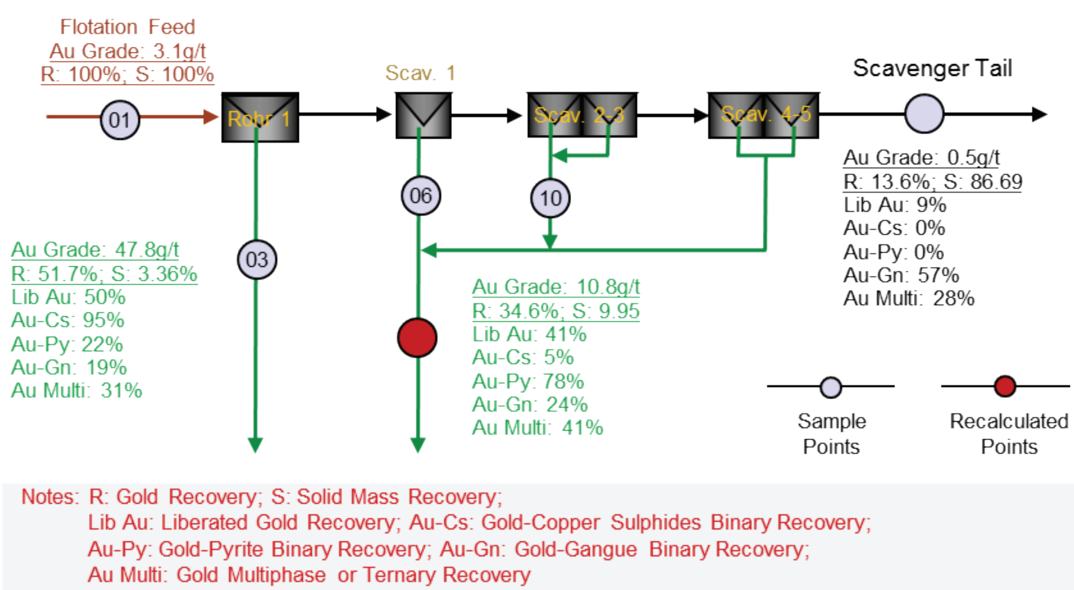


Figure 4. Schematic flowsheet of gold recoveries by streams by association classes

The mineral recoveries by class and by particle size range charts (See Figure 5) reveal that the gold losses through the rougher-scavenger circuit was dominantly ascribed to the finely grained liberated gold (sized finer than 10µm) or the unliberated gold (locked with non-sulphide gangue in binary or multiphase forms). As anticipated from the feed, this loss of gold-gangue binaries was distributed across all particle sizes, but primarily in the particle size of greater than 106µm.

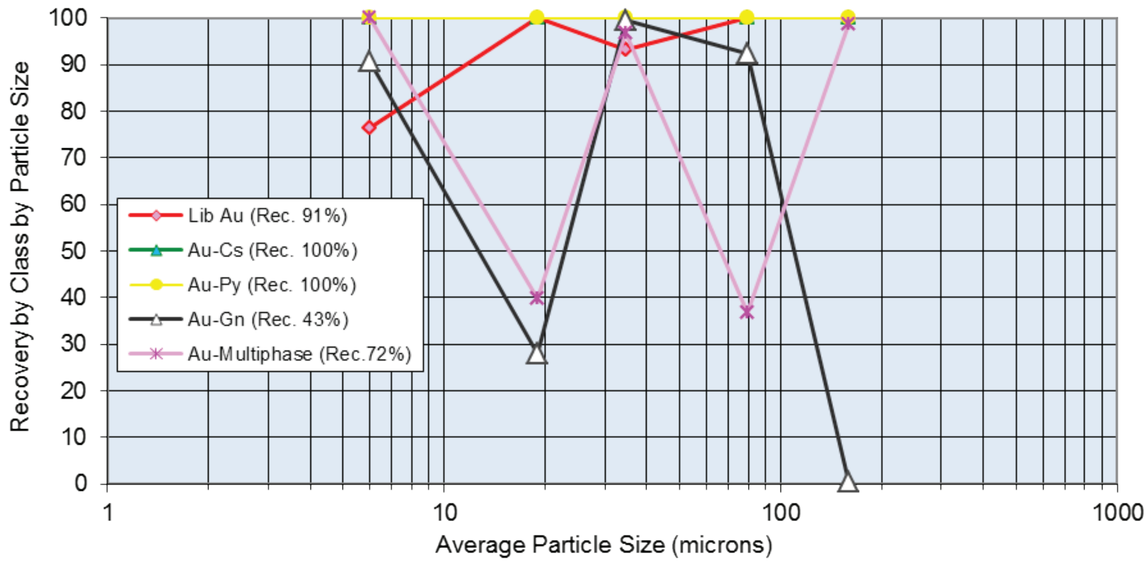


Figure 5. Gold recovery by class and by particle size, Rougher - Scavenger Circuit

Regrinding Circuit Performance

The scavenger combined concentrates were reground ahead of feeding into the cleaner circuit. The effects of regrinding on the mineral liberations of regrinding streams are shown in Figure 6. As shown in Figure 6, about three quarters of solids mass in the regrinding feed (scavenger combined concentrates) was split into cyclone underflow and fed into Isa mill. The cyclone underflow assayed 12.9g/t gold and contained 87.4% of gold in the regrinding circuit feed.

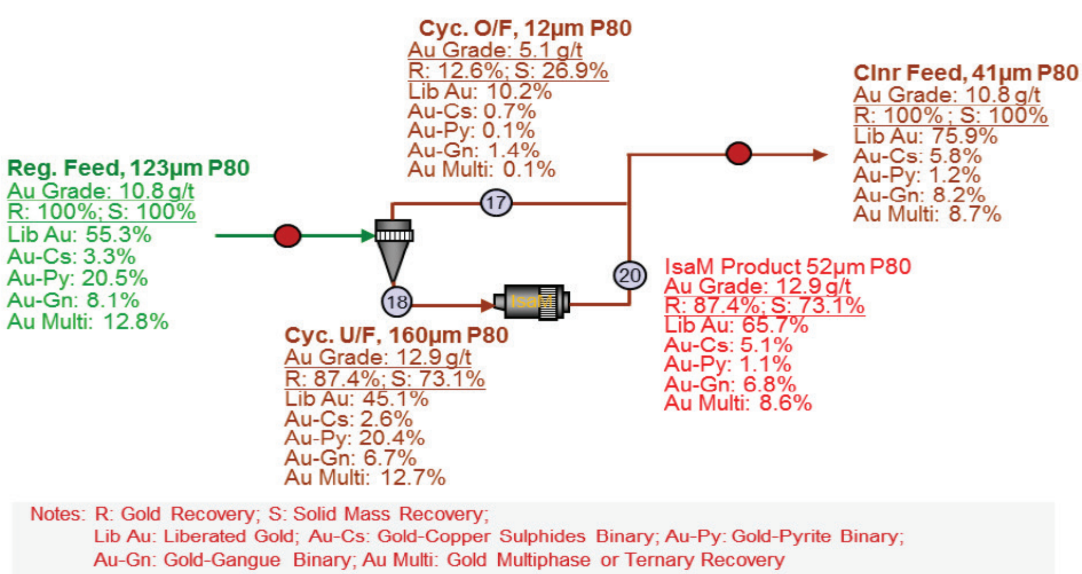


Figure 6. Regrinding circuit metallurgical – mineralogical performances

During regrinding, the liberations of gold and sulphide minerals were improved significantly. Comparing the mineral liberations of the cyclone underflow and the Isa Mill products, the gold liberations increased by over 20%, from 51.5 to 75.1%.

The mineral liberations of the regrinding feed and the cleaner feed were particularly calculated based on the metallurgical balances and the mineral liberations of cyclone overflow, cyclone underflow and Isa Mill products. Averaged increment in gold liberation was 20.6%, from 55.3% of the regrinding feed to 75.9% of the cleaner feed. This was mostly due to the decreased amounts of gold-pyrite binary and gold multiphase composites (See Figure 6).

Cleaner Circuit Performance

The cleaner circuit captured about 30.1% of solids from the circuit feed into the cleaner circuit concentrates, including rougher cleaner concentrate and scavenger cleaner concentrate. As a result, 97.5% of the gold in the circuit feed stream was recovered into cleaner combined concentrates (See Figure 7).

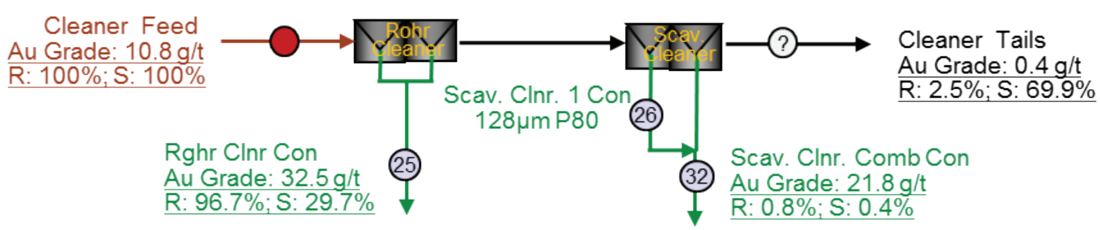


Figure 7. Cleaner circuit flowsheet and metallurgical balances

Quality of the Final Concentrate

The final concentrate was generated from both rougher and cleaner circuits, in the mass ratio of close to 11. The gold and mineral contributions of each stream to the final concentrate are presented in Table 2 and Table 3.

Products	Mass	Mineral Composition (wt. %)							Mineral Distribution (%)						
	%	Au	Ac	Cs	Ga	Sp	Py	Gn	Au	Ac	Cs	Ga	Sp	Py	Gn
Rougher 1 Con	52.9	47.8	0.03	7.63	0.99	4.58	69.5	17.2	60.5	68.9	75.1	64.1	66.4	58.0	34.1
Rghr Clnr Comb Con	46.5	35.2	0.01	2.86	0.63	2.63	57.0	36.8	39.2	30.6	24.7	35.8	33.4	41.8	64.1
Scav Clnr Comb Con	0.6	21.8	0.02	0.97	0.23	1.11	23.9	73.8	0.3	0.4	0.1	0.2	0.2	0.2	1.8
Recalculated Final Con	100.0	41.8	0.02	5.37	0.82	3.65	63.4	26.7	100	100	100	100	100	100	100

Table 2. Final concentrate circuit mineralogical balance

Mineral Status	Recalculated Final Con	Overall Gold Deportment			Gold Distribution by Class		
		Rougher 1 Concentrate	Rghr Clnr Comb Con	Scav Clnr Comb Con	Rougher 1 Concentrate	Rghr Clnr Comb Con	Scav Clnr Comb Con
Liberated Au	**53**	27.1	25.3	0.3	51	48	0.5
Au-Cs Binaries	**26**	24.6	1.0	0.0	96	4	0.0
Au-Sp Binaries	**1**	0.0	0.7	0.0	0	100	0.0
Au-Py Binaries	**9**	2.4	6.2	0.0	28	72	0.2
Au-Gn Binaries	**4**	2.6	1.0	0.0	72	27	0.4
Au-Multiphase	**9**	3.8	5.1	0.0	43	57	0.3
Total	**100**	60.5	39.2	0.3			

Table 3. Gold distribution by concentrate stream and by association class

Pyrite and non-sulphide gangue, combined accounting for 90.1% of the concentrate mass, were the main diluting minerals in the final concentrate. It is of importance to note that majority of pyrite and non-sulphide gangue in the final concentrate were either liberated or associated with each other (See Figure 8 and Photomicrographs).

The limiting grade recovery curves indicates that the copper grade can be theoretically improved by over 15% by rejecting these liberated pyrite and non-sulphide gangue without any further regrinding. However, this may sacrifice the gold recoveries since significant interlocking between gold and pyrite was observed in the final concentrate. As a result, the metallurgical tests will be required before any actions are taken, such as further depressing pyrite and non-sulphide gangue, in order to improve the copper grade.

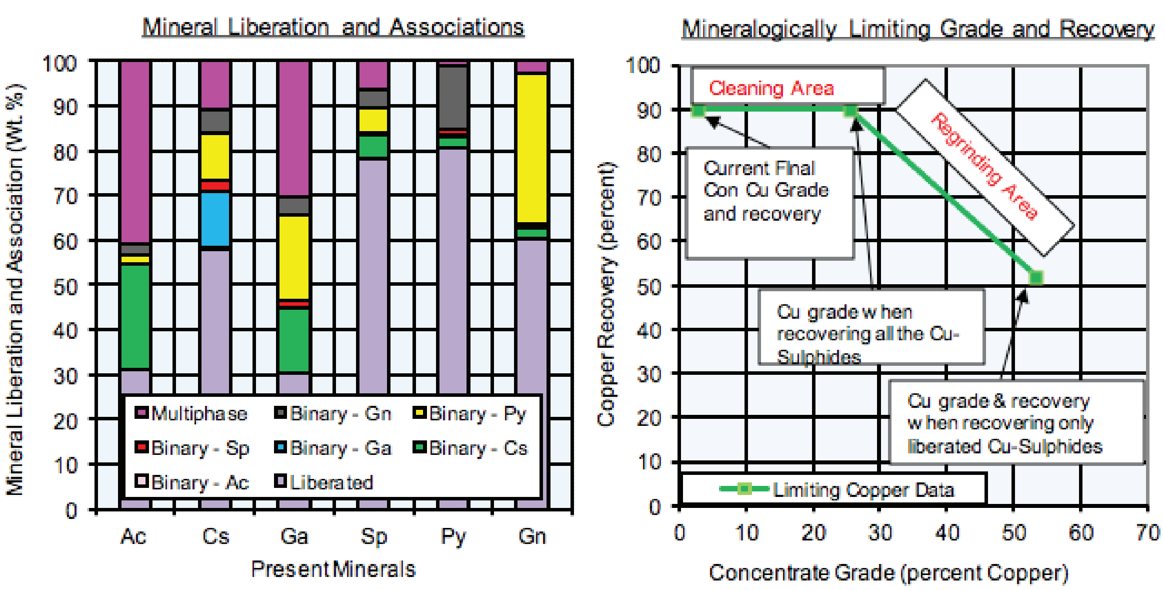
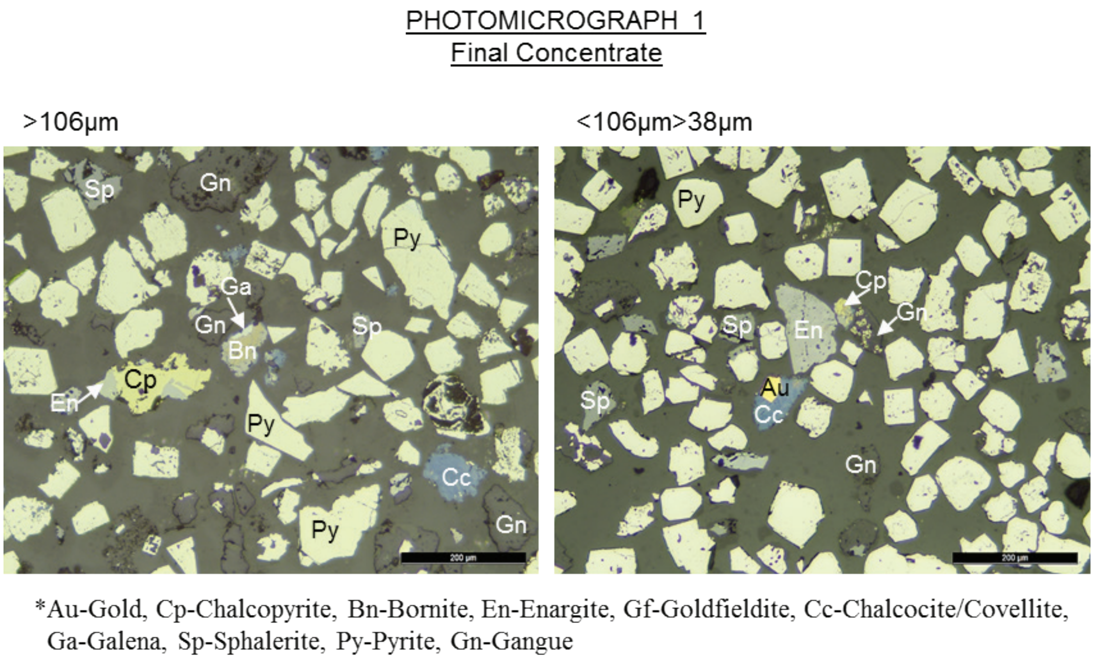


Figure 8. The quality of the final concentrate. Notes: 1) Ac-Acanthite including other silver minerals, Cs-Copper Sulphides including Enargite, Chalcopyrite, Chalcocite/Covellite and bornite, Ga-Galena, Sp-Sphalerite, Py-Pyrite, Gn-Gangue



Photomicrograph 1: Au-Gold, Cp-Chalcopyrite, Bn-Bornite, En-Enargite, Cc-Chalcocite/Covellite, Ga-Galena, Sp-Sphalerite, Py-Pyrite, Gn-Gangue.

Gold Losses

The gold losses into the process tailings were determined in this study and the results of this assessment are presented in Figure 9. Totaling 14.5 % of the feed gold was lost into the final tails. The results generated from the laser ablation ICP-MS analysis on the selected minerals, such as pyrite, indicate that 99 % of these gold losses were present as visible gold. Close to 30% of the lost gold occurred as liberated particles, which principally located in the finer particle size range of less than 10µm.

The gold distribution by grain size data (Figure 9B) further reveals that 96% of the gold occurrences were measured at size finer than 10µm in circular diameter. The remaining gold in the final tails was dominantly locked with non-sulphide gangue in binary or multiphase forms, typically containing less than 10% by area gold (See Figure 9C). These locked gold grains were distributed in relatively coarser size fractions of greater than 106µm, and associated with large pieces of non-sulphide gangue (Figure 9A).

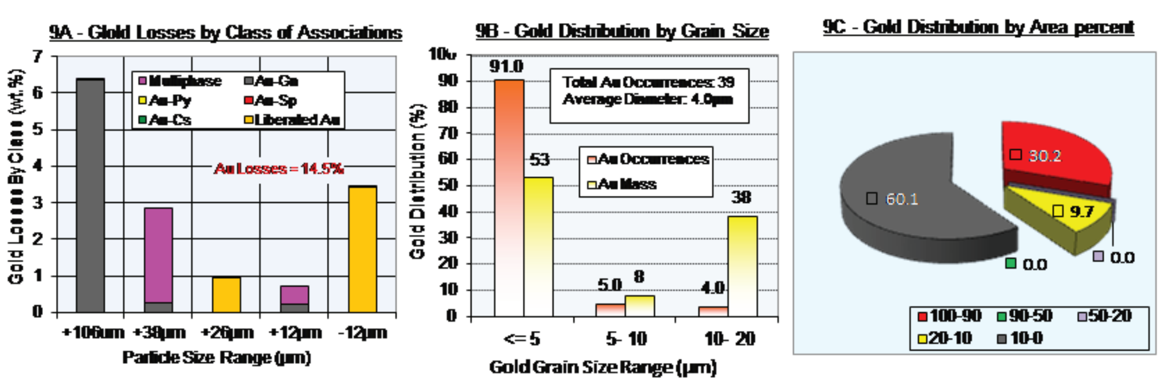


Figure 9. Mineralogical characteristics of the gold losses in the final tailings

CONCLUSIONS

Fine grained gold, locked with greater than 106μm in particle size of non-sulphide gangue, may be the sources of gold losses during the flotation. The effectiveness of the regrinding circuit, through the selective breakup of gold-pyrite binary and gold multiphase composites, was also confirmed in this study. The potential to improve the concentrate quality can probably be accomplished by improved rejection to tailings of the mostly liberated pyrite and non-sulphide gangue minerals. To improve the gold recovery, improving the flotation selectivity of finely grained gold or finer primary grinding will be required.

These studies can and are used widely to assess process performance and increasingly are being used to examine drill core samples to design metallurgical test programs and to better predict ore responses across a range of conditions. We have successfully support the flotation condition optimization of the plant operations of Phu Kham mine in Laos, Fresnillo Mine and La Cienega Mine in Mexico, and metallurgical testing on various ore samples at BV Minerals in Canada and JK Tech Pty. in Australia.

ACKNOWLEDGEMENTS

We are thankful to JK Tech Pty Ltd and Mt. Carlton in Queensland of Australia for allowing use of the flotation flowsheet, metallurgical balances and mineralogical data.

The corresponding author would like to give the thanks to Mr. Peter Brown, P.Eng, consulting metallurgist (G&T Metallurgical Services in Kamloops), for reviewing this paper.

The authors would like to acknowledge the fundamental work by Dr N W Johnson of CSIRO and Peter Munro (Mineralurgy Pty. Ltd. in Australia) in developing the process mineralogy techniques at MIM (Mount Isa Mine in Australia) many years ago.

The authors also wish to thank Mr. Craig Kenna, VP Commodities - Pacific Zone and Mr. Alex Christ, ICP-MS Manager - Pacific Zone at Bureau Veritas Australia Pty Ltd for the support of Laser Ablation ICP-MS analysis on the pyrite of final concentrate sample. Thanks to Professor Mati Raudsepp at University British Columbia for the X-Ray Diffraction (XRD) analysis and electron microprobe analysis.

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