GRAVITY CONCENTRATION OF GOLD FROM BASE METAL FLOTATION MILLS

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INTRODUCTION

Gold, because of low head grade and recovery, is usually of minor importance in the economics of poly-metallic base metal ores. TABLE 1 presents gold heads and recovery for some of Noranda's base metal mills. It should be noted that the stated recoveries are to payable concentrates, but does not reflect the actual payable gold recovery which in some cases is significantly lower. Noranda's average gold recovery into gold payable concentrates is about 45%. This equates to a collective loss in the order of $57 MM per year of gold

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ABSTRACT

Gold, because of low head grade and recovery, is usually of minor importance in the economics of base metal flotation mills Because of the above, little metallurgical attention is usually provided to gold in these mills. But collectively, the gold losses can be significant. For instance, Noranda presently has interest in 13 base metal flotation mills with a collective gold recovery of only 50%. Gold losses are in the order of 150,000 oz per year!

The Noranda Technology Centre, in cooperation with Noranda's milling operations, has been investigating the potential of gravity concentration of gold from base metal flotation mills. This paper outlines the pilot and plant testing conducted at three operations with distinctly different ore types; porphyry copper, complex massive sulphide and polymetallic semi-massive sulphide. Testing has been with the Knelson Concentrator which has proven to successfully recover fine gold in a simple, trouble free circuit. Discussion of issues which have risen from the testwork is included

TABLE I: GOLD HEADS and RECOVERY in SOME NORANDA MILLS

Mill	Heads, ppm	Recovery. %	oz. Lost/Year
Bell	0.2	55	16,000
Brunswick	0.6	12	59,000
Heath Steele	0.5	15	14,000
Matagami	0.5	40	7,000
Mattabi	1.0	55	4,000
Samatosum	2.0	80	3,000
Westmin Myra Falls	2.0	50	40,000
Average/Total		45	143,000
$$$			$57 MM

Note: *denotes gold to several payable concentrates

The gold losses can be attributed to any or all of the following reasons:

- refractory (mineral solid solution) gold
- unliberated
- too coarse for flotation
- smeared onto other particles
- other particles embedded into gold
- flotation conditions incorrect for gold flotation

Gravity concentration is one technique which can augment flotation recovery of gold, particularly if losses are attributed to the final four points listed above. Although gravity concentration is an old technique, it is seldom applied in flotation mills because: the gold tends to be fine (< 150 urn), complicated labour intensive circuits were required and, the machines to overcome these deficiencies were not available. Development of the Knelson Concentrator has potentially alleviated some of these deficiencies.

There are several issues and questions which must be addressed when embarking upon a gravity concentration test program. Important questions and issues are:

- is there an easy way to determine if gravity concentration has potential ?
- what is to be demonstrated by a gravity test program ?
- can plant results be predicted from lab tests ?
- what scale of testing is necessary ?
- how do you determine if a gravity circuit is beneficial ?
- what do you do with the gravity concentrate produced ?

These points will be addressed and three gravity concentration test programs will be discussed in the paper.

THE KNELSON CONCENTRATOR

The Knelson Concentrator was selected for testing because previous experience with the unit had demonstrated excellent performance[1,2]. Briefly, the unit is a centrifugal bowl concentrator with a water jacket around the bowl, essentially a modified centrifuge (FIGURE 1). Feed slurry enters the rotating ribbed bowl where heavier particles are trapped between the ribs. Compaction of the material between the ribs is prevented by injecting water through holes in the bowl. The water fluidizes the bed and allows heavier particles to continuously displace lighter particles. The water addition is the key to the performance of the Knelson Concentrator. The degree of fluidization (water back pressure) essentially controls the concentrate bed bulk SG and porosity and hence the ability to control which minerals will or will not report to the bed. As a general rule of thumb, lower pressures are used for low SG gangue material and higher pressures for high SG gangue minerals. Higher pressures will be required for coarse particles as more water will be required to fluidize a bed of greater porosity. The machine is semi-continuous, ie. the machine must be stopped every several hours to remove the concentrate. Clean-up time is approximately 10 minutes.

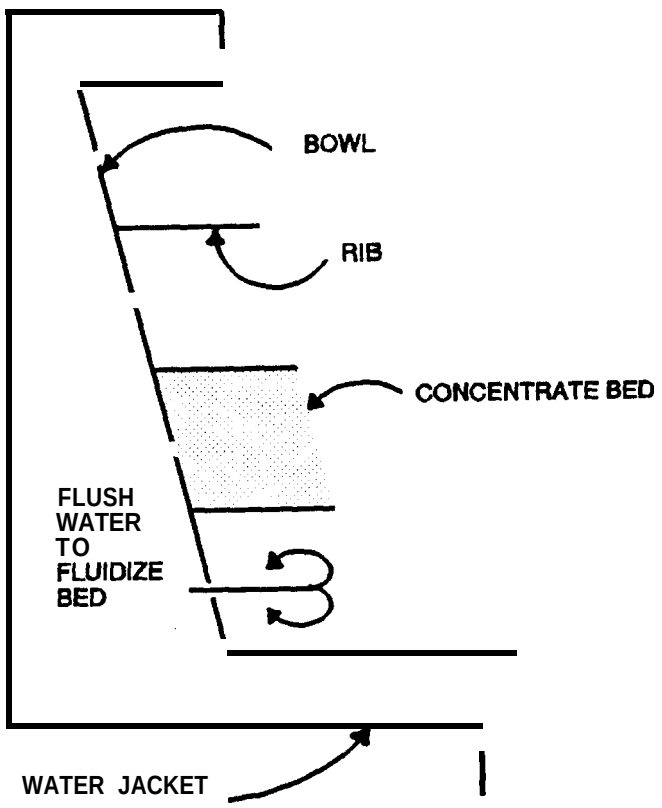

Figure 1: Cut-away Schematic of a Knelson Concentrator

PRELIMINARY SAMPLING TO DETERMINE IF GRAVITY CONCENTRATION IS POSSIBLE

There are two factors to consider prior to embarking on a gravity concentration test program. First, are the gold losses sufficient to justify the testing and potential implementation of a gravity circuit, ie. losses are measured in the '000's of oz. per year? Secondly, is the gold free and recoverable by gravity techniques? This second point can be easily determined by assaying the grinding circuit cyclone O/F and U/F streams for gold. If the gold's ratio of concentration from cyclone O/F to U/F is greater than the other elements or minerals (or about two times) then the gold must be free and as some form of gold alloy. TABLE II provides assay data around grinding cyclones for some Noranda's operations. Of these operations, only Geco shows little potential for gravity concentration. The ratio of concentration at Geco was mid way between that of Cu and Fe suggesting that the gold is likely in solid solution with chalcopyrite and the Fe sulfides in the ore. At other operations, such as Bell, the U/F is enriched with gold in comparison to the other minerals. Testing at Heath Steele and Bell has demonstrated the feasibility of gravity concentration from plants with a low gold ratio of concentration in the grinding cyclones. Although the number plants tested to date is limited, it is felt that a higher ratio of concentration indicates a greater potential for gravity concentration.

TABLE II: GOLD ASSAYS IN SOME NORANDA GRINDING CIRCUITS

	Assay, ppm Au		
Operation	Cyclone O/F	Cyclone U/F	Ratio of Concentration
Bell	0.33	0.48	1.8
Geco	0.16	0.22	1.4
Heath Steele (Primary)	0.72	1.47	2.0
(Secondary)	0.66	2.19	3.3
Hemlo	16.0	400	25.0
Matagami	0.51	5.60	11.0
Westmin Myra Falls	2.00	11 .00	5.5

PILOT TESTING

Pilot scale testing was carried out with a 7.5' Knelson Concentrator. This scale of testing was used to demonstrates that free gold can be recovered from the grinding circuit by gravity techniques. Knelson concentrate was panned to provide visual proof of the gold. From these tests an estimate of plant scale gravity circuit gold recovery can be made. The estimate is crude, but can provide an indication if a plant scale test is warranted. The scale up criteria is the unit recovery which is applied to the tonnage and feed grade of material to be processed through the plant scale unit. This calculation provides an estimate of the gold recovery per hour and hence gold recovery to gravity concentrate can then be determined from the mill feedrate and Au heads.

For example:

g/hr=	1	x	25	x	1	x	20%	=	5g/hr
	# of Units		TPH Feed		Feed, ppm Au		Unit Recovery		

and for % gold recovery:

Mill Feed at 100 TPH and 0.5 ppm Au (50 g/hr Au)
Gravity circuit recovery 5 g/hr

Therefore gravity circuit Gold recovery = 10%

Pilot scale testing does not answer the key question of whether the gold recovered to gravity concentrate is from non-paying mill products (ie. tailings) or taken from a high paying flotation concentrate (ie. Cu concentrate). The purpose of a gravity test program is not to determine if gold can be recovered by gravity techniques, but whether gravity concentration can improve the revenues received from gold, ie. favourably redistribute the gold between mill products. Only a plant scale test can provide this information and thus plant scale testing must be conducted as part of a gravity concentration test program. This is not say that pilot scale testing should be eliminated. Pilot scale testing provides an important bridge between assaying cyclone products and carrying out plant tests, particularly if the grinding gold circulating load is not very high (<3) or plant flotation recovery of gold is low and few people in your operation believe there is free gold in the ore. Also, pilot testing has the intangible benefit of bringing management onside for plant scale testing quickly. It is amazing the visual effect a few flakes of gold in the bottom of a gold pan has! Of the three operation discussed in the paper, Westmin skipped over the pilot stage as they were aware that at least some of the gold in the ore was free and the circulating load in the grinding circuit was high. They were confident that gold could be recovered by gravity techniques. On the other hand, testing at Bell and Heath Steele required a pilot scale test program to demonstrate that sufficient gold could be recovered by gravity concentration to warrant a plant test. I do not believe either of these two operations would have opted for a plant test based just from the grinding circuit gold circulating load. In summary, if there is great confidence that gold can be recovered by gravity techniques then pilot scale testing can be skipped over. For most operations a pilot scale test program is necessary to determine if plant scale testing is warranted.

Tailings streams have been pilot tested at two operations, one with a high gold circulating load and one with a lower circulating load. In both cases the results were disappointing, both grade and recovery being very low. It was hoped that testing of tailings streams could provide an indication of enhanced gold recovery by gravity concentration. Unfortunately tailings streams provided no indication of the potential for gravity concentration based on our test results. Thus it is not recommended to focus a gravity test program on the flotation streams. The focus should be on the grinding circuit where the gold is still relatively coarse and easy to recover, and the pre-concentration through the cyclones can be taken advantage of.

PLANT SCALE TESTING

As mentioned above, this scale of testing MUST be conducted to determine the change in gold distribution between mill products as a result of a gravity circuit. Gold robbed from high paying flotation concentrates will not justify the capital required to install a gravity circuit.

From our initial testwork it was apparent that full scale testing was required to properly evaluate whether gravity concentration was beneficial. Noranda worked with Knelson International Sales to put together a rental plant scale test circuit to carry out this testwork. The test circuit essentially duplicates the 7.5" pilot plant, consisting of a 3' x 8' screen deck mounted above a 30" Knelson Concentrator. The test circuit has a footprint of approximately 6' x 10' and a height of 12' split into two stacking modules. Cyclone U/F is fed onto the screen deck with the U/S being the Knelson feed. Screen O/S and Knelson tails are combined and returned to the cyclone feed pump box.

A test program first focuses on "optimizing" the process variables, run time and water pressure. Once the operating conditions have been determined an extended test is conducted so a statistically valid comparison between before and after gravity circuit gold distributions can be made. This test can only commence after the rig has operated for a period to deplete the gold circulating load. Experience shows this depletion period to be less than 24 hours, depending on the fresh gold feedrate and hold up in the grinding circuit. At time of printing, Westmin has completed a plant scale test and Bell Copper is in the process of conducting a plant scale test. Heath Steele Mines will conduct a plant scale test early in 1992 when the test circuit becomes available.

DETERMINING A SHIFT IN PLANT GOLD BALANCE

One major problem arising from the work is in how to determine the shift in gold distribution between mill products as a result of a gravity circuit. Certainly an extended plant test is required to determine a statistically valid shift in plant gold balance, but what mill products should be followed ? The following questions arise; does the ore mineralogy change, the effect of changing mill heads, changing concentrate grades, assay accuracy, etc ? All are important concerns which must be addressed in convincing management that gravity concentration is a good addition to the mill.

Three ways to compare the effect of the gravity circuit on mill gold distribution have been tried:

- comparing gravity test period total payable gold with the year to date value
- comparing gravity test period total payable gold with a value determined by regression of head assay and concentrate assay values to try and account for variable head assays and concentrate grades,
- conduct extensive mill sampling before and after gravity testing and determine a shift in gold distribution from the mass balanced data.

Respectively, each method above has an increasing workload which may or may not provide a more accurate comparison. Westmin conducted detailed Cu circuit sampling during their extended run so the shift in gold balance could be followed with time. But, their main analysis was based on the change in Cu concentrate Au content from gravity concentration in comparison to the year to date value. The two methods did not completely agree and Westmin used the more conservative result for their capital requisition. The regression technique was briefly evaluated but it could not fully account for the changing Au assay in the Cu concentrate and was deemed no better that the other two methods.

Another consideration is the magnitude in change of assay which results from the gravity circuit. At some operations, the gravity circuit may only change concentrate assays by 0.2 ppm or tailings assays by less than 0.1 ppm. If the daily standard deviation of concentrate gold assays is 0.5 ppm Au or assay accuracy is only 0.1 ppm Au then it will be difficult to prove the effect of a gravity circuit on gold distribution. Bell is such an example. Bell is expected to recover about 1% of the gold in the mill feed to gravity concentrate. Current flotation Au recovery is 60% which results in a relative change in concentrate assay of about 2%. The Cu concentrate typically assays 10 ppm Au and thus the test program will look for a maximum change in Cu concentrate assay of about 0.2 ppm. The change in tailings assay will be a maximum of about 0.05 ppm Au. Thus, the magnitude of changes in assay as a result of gravity testing may be quite difficult to detect and statistically prove.

In summary, it can be difficult to conclusively demonstrate the effect of a gravity circuit on the plant gold distribution. It is suggested that careful consideration be given in how to evaluate the effect of the gravity circuit on plant gold distribution.

GRAVITY CONCENTRATE - TO SELL OR MAKE BULLION

This is apparently a difficult question. Many operations consider producing bullion from their gravity concentrate and avoid selling the concentrate as is. The reasons for producing bullion are: to receive a higher payment for the gold, decrease gold inventory and avoid losses from sampling error. These are all valid reasons for producing bullion from gravity concentrate at gold mines, but I am not sure they are that completely valid at base metal flotation mills because of the relatively small amount of gold produced at these mills.

The increase in payment from concentrate to bullion is in the order of only 3%. In most flotation operations this 3% will generally not support the operating costs required to produce bullion. The reduction in inventory is realized through the difference in payment terms received from smelters and refiners. Smelters typically pay in 90 days while refiners usually pay in 60 days. The amount of gravity gold production produced in one month is most likely insufficient to cover the capital required to set up bullion production facilities.

Thus, it is suggested that during the gravity test program focus on making gravity concentrate and assume that the gravity concentrate will be sold. Once a gravity circuit has demonstrated its benefits and is functioning well, then production of bullion can be considered. Gravity concentration and bullion production are separate items so do not try to bring them together for one project.

PLANT TESTING

Westmin Myra Falls

Westmin's Myra Falls operation is a 3500 TPD mine located centrally on Vancouver Island, 'British Columbia. The ore is 50% sulfides made up primarily of chalcopyrite and sphalerite in a pyrite matrix. The ore contains appreciable gold values, 2 g/t, but only about 35% of this is recovered to the Cu concentrate and about 15% recovered to the Zn concentrate. It was suggested to Westmin that they sample the O/F and U/F of the cyclone to determine the circulating load of gold to see if gravity concentration would have any promise. The initial sampling indicated a circulating load of 1700%. Following sample campaigns indicated circulating loads of 1200% to 1500% to be typical. Westmin made contact with Knelson and together they conceived the plant scale test rig. They opted to go directly to plant scale testing because they felt confident that gold could be recovered by gravity techniques and that they needed to find out how a gravity circuit would influence the mill gold balance. The test circuit was assembled and commissioned the first week of June, 1991. The test circuit withdrew 10 TPH of cyclone U/F from one of the two grinding circuits. Initial testing focused on optimizing the run time and the water pressure. Optimum conditions appeared to be 8 hours run time between cleaning at a water pressure of 6 PSIG. Westmin then conducted a 96 hour continuous test to determine the effect of the gravity circuit on the plant gold distribution. TABLE Ill presents the mill gold balance with and without the gravity circuit. Westmin4 found that the gravity circuit recovered about 5.5% of the gold in the mill and overall the gravity circuit improved plant gold recovery by 3.3%, ie. some of the gold recovered to gravity

TABLE Ill: Effect of Gravity Circuit on Westmin Gold Balance

(Before/After)

Stream	Assay pprn Au	Distribution %
Feed	2.34 / 2.22	100 /IOO
Gravity Con	0 / 2400	0 / 5.4
Cu Rfr Con	7.4 / 6.4	49.5 / 45.2
Cu Rfr Tail	1.4/ 1.3	50.5 / 49.4
Cu Clnr Con	II.O 10.2	33.9 / 31.8
Cu Clnr Tail	4.4 / 2.7	15.7 / 13.4

concentrate would have reported to the Cu concentrate if the circuit was not in place. Several streams had notable changes in gold assay. The ratio of concentration of gold in the grinding cyclones dropped from 5 to 3. The Cu cleaner tails assay also decreased significantly. Hence the gold recovered by the gravity circuit would have been recovered in rougher flotation, but most of this would be lost through cleaner flotation. The increase in gold recovery is primarily due to lower cleaner losses. Also, it appears that this "extra" 3.3 %recovery came from the tailings as no change in Zn concentrate gold assay was noticed.

The gold recovered at Westmin was relatively coarse in comparison to the other operations investigated to date. Westmin has 50% of the gravity recovered gold finer than 100 mesh and appreciable quantities up to 10 mesh in size. Westmin has contemplated the various options to handle the gravity concentrate produced.

Options considered are:

- sell the gravity concentrate to a smelter,
- send the concentrate to their sister mine Premier Gold in Stewart for direct smelting,
- carry out processing of the concentrate on site (intensive cyanidation, direct smelting, etc.).

On site processing of concentrate has been ruled out because of the high cost associated with having a dedicated person to process the concentrate. Their marketing arm is investigating the preferred route of the other two options. Another consideration is whether to further upgrade the concentrate. The 3O"concentrate was further upgraded in a 7.5" Knelson concentrator from 2000 ppm Au up to 8000 ppm at > 90% recovery. This small tonnage of high grade concentrate could then be sent to the Premier operation while the 7.5" Knelson tails could be either returned to the grinding circuit or sent directly to the Cu concentrate thickener as it assayed from 50 to 100 ppm Au, much higher than Cu concentrate itself. The main concern from this option is sampling accuracy of a pulsed gravity concentrate flow into the continuously fed Cu concentrate thickener, ie can the gravity concentrate be accurately accounted for ? Westmin is proceeding with the installation of a permanent gravity circuit. Part of their consideration is the installation of Knelson newly developed self cleaning machine which essentially eliminates operator attention.

Bell Copper

Noranda's Bell Copper mine is located in central British Columbia and is a typical porphyry copper type deposit. The main ore mineral is chalcopyrite and the ore has a total sulfide content of about 4%. Bell has a higher than average gold head of 0.25 g/t Au. Their historic gold recovery has been in the order of 55% to the Cu concentrate. Bell was aware that the gravity testing at Westmin was looking promising and conducted several surveys around their grinding cyclones to determine their gold circulating load.

TABLE IV: Size Fractional Data from Bell Copper Pilot Gravity Concentrate

Size Fraction	Cyclone U/F wt% passing	Assay, ppm Au	Au Distribution, % Passing
+841 um	80.0	3	99.3
+296 um	45.8	9	95.1
+150 um	23.1	84	71.8
+37 um	7.1	570	14.2
-37 um		1517	
Head		97	

The average of the sample campaigns indicated a ratio of concentration just under 2. The results of these surveys were interesting, but it was felt could only warrant testing the 7.5" Knelson pilot plant as it was uncertain if significant free gold was present at such a low ratio of concentration.

A series of 6 pilot scale tests were conducted in early August to assess the potential of a Knelson based gravity circuit. The pilot Knelson circuit obtained >10% unit recovery and produced a concentrate up to 200 ppm Au from 1400 kg of cyclone U/F. Screening of the gravity concentrate (TABLE IV) indicated that the recoverable gold is 70% passing 100 mesh (150 µrn) while the cyclone U/F is typically only 23% passing 100 mesh. From these tests it was estimated that 1000 oz/yr Au could be recovered and that a plant scale test should be conducted to confirm this figure and assess if this gold was enhanced recovery or just taken from the Cu concentrate. The plant scale test circuit was commissioned the first week of November. The gravity circuit at Bell has the feed screened on 35 mesh (425 µrn) where as at Westmin the screening was carried out on the standard 10 mesh (1690 µrn). It was felt that finer screening should:

- improve the unit recovery as fine gold should more easily displace gangue particles of similar size,
  permit a higher feedrate (both solids and gold) to the circuit while maintaining Knelson solids feedrate but increasing gold feedrate to the Knelson.

The circuit had a feedrate of 30 TPH to the screen deck and about 10 TPH feeding to the Knelson Concentrator. From the preliminary tests the Knelson is recovering 1.5 g/hr into a concentrate assaying from 500 to 1000 ppm Au, similar to that estimated from pilot scale testings. Bell has found that the concentrate produced from the 30" Knelson can easily be upgraded in the 7.5" pilot unit. The 30" concentrate can be upgraded to 9000 ppm Au with a gold recovery of 80 to 90 %. The 7.5" Knelson tails run 50 - 100 ppm Au and could then be pumped to the concentrate thickener. The gravity concentrate produced would be sent to Noranda's Horne smelter where any error in sampling still remains in the company. At Bell only a few tonnes of gravity concentrate would be produced per annum. Bell is presently conducting the long term testing required to determine the effect on the plant gold balance.

Heath Steele

The Heath Steele mine is located in central New Brunswick and is a typical fine grained massive sulfide deposit from the region. The main ore minerals are sphalerite, galena and chalcopyrite in a pyrite matrix with the ore having a sulfide content of about 90%. The mill feed averages 0.5 g/t Au. The historic payable gold recovery has been in the order of 15% to the Cu concentrate, but with deductions and refining charges the actual payment received was less than 10% of the gold in the ore. The Pb and Zn concentrates also have some contained gold but there is seldom any payment for it in these products. Since the gold payment was always very low it was always assumed that the gold was refractory. The geologist had never seen any visible gold in the ore and microscopy had never indicated any free gold in mill products. The Knelson testing at Westmin prompted Heath personnel to sample their grinding circuit to determine if there was a gold -circulating load and hence the possibility for a gravity concentration circuit. The survey very surprisingly indicated gold circulating loads in both the primary and secondary grinding circuits (TABLE V). A series of pilot scale tests were conducted in September from both the primary and secondary grinding mill discharge to assess the potential of a Knelson based gravity circuit. The pilot Knelson circuit obtained up to 20% unit recovery and produced a concentrate assaying 500 ppm Au from 3 tonnes of cyclone U/F. It was estimated that Heath could recover 2000 oz/yr gold with a gravity circuit. Heath Steele will be testing the plant scale Knelson circuit in early 1992 to fully assess the impact of a gravity circuit on the plant gold distribution. The shift in gold distribution at Heath will be relatively easy. At present they receive Au payment only from Cu concentrate. The amount of gold recovered to Cu concentrate will be only about twice that of the gravity circuit. Therefore, if the gravity circuit recovers gold which normally would have reported to the Cu concentrate the change in Cu concentrate Au assay will be quite dramatic.

TABLE V: Gold Assays in the Heath Steele Grinding Circuit

Size	Au Assay, ppm		Ratio of	Au Assay, ppm		Ratio of
Fraction	PC0	PCU	Concentration	SC0	SCU	Concentration
+150 um	0.38	1.13	3.0	0.16	0.25	1.6
+105 um	0.59	1.38	2.3	0.19	2.91	15.3
+74 um	0.88	3.47	3.9	0.38	2.22	5.8
+53 um	0.75	2.60	3.5	0.63	2.47	3.9
+37 um	0.65	2.47	3.8	0.72	2.41	3.3
-37 um	0.78	0.85	1.1	0.69	1.91	2.8
Head	0.72	1.47	2.0	0.66	2.19	3.3

A key thing learned from Heath Steele is that the potential for gravity concentration should not be gauged from low gold recovery to flotation concentrates. Sampling and assaying the grinding cyclone products to determine the gold circulating load is far more relevant in assessing the potential for gravity concentration.

CONCLUSIONS

1. Fine (-100 mesh) free gold/electrum can be recovered by gravity techniques from the grinding circuits of base metal flotation mills. This gold generally cannot be recovered successfully from the flotation streams.

2. The ratio of concentration for gold in a cyclone is an excellent way to quickly determine if gravity concentration is possible. If the gold is concentrating to the U/F then it must occur **as** a free gold bearing alloy.

3. If the concentration of gold to the cyclone U/F is high then pilot scale testing can be skipped in favour of plant scale testing.

4. An estimate of the gold recovered to **a** gravity concentrate can be made from pilot scale tests. This scale of testing cannot predict the distribution of gold between mill products though.

5. Plant scale testing must be conducted to determine the effect of a gravity circuit on the plant gold distribution. The gravity circuit must improve the plant payment for gold, not just recover gold into a gravity concentrate.

6. Determination of a statistically valid shift in the plant gold distribution as a result of a gravity circuit is the most difficult task with the testing of gravity concentration. Extended testing must be conducted and the samples and method of comparison must be carefully chosen.

7. The method of handling gravity concentrate is plant dependent. Plants with gold treatment or with significant gravity gold production may find bullion production advantageous. But, most base metal flotation mills will find it advantageous to sell the gravity concentrate for outside processing into bullion.

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