Search

PAPER 7

The Gravity recoverable gold test and flash flotation

André Laplante[1]
Robert C. Dunne[2]

[1]McGill University
Department of Mining, Metals and Materials Engineering
3610 University St., Wong Building
Montréal, Québec, Canada
H3A 2B2
PH: (514) 398-1281
Fax: (514) 398-4492
E-mail: alapla2@po-box.mcgill.ca

[3]Newcrest Mining Limited
The Hyatt Centre, Level 2
Plaza Level West
East Perth, Western Australia 6004
Australia
PH: (618) 92707051
FAX: (618) 9221-7338
E-mail: robd@newcrest.com.au

Keywords: flotation, flash flotation, GRG, BCC, recovery, gravity recovery

Proceedings
34th Annual Meeting of the
Canadian Mineral Processors

January 22-24, 2002
Ottawa, Canada

ABSTRACT

The role of flash flotation in precious metal recovery is reviewed. Interacting flash flotation and gravity recovery is discussed. The GRG test can be used, when linked to the behaviour of gold in grinding and classification units, to predict the recovery of GRG by flash flotation. The Cadia mill in New South Wales is used as a case study of circuit design, performance and simulation. It is shown that high throughput coarse grind applications such as Cadia require very effective fine GRG recovery systems in the primary grinding loop, which are more consistent with flash flotation than batch centrifuge concentrators (BCCs). BCCs can effectively recover a significant fraction of the GRG from flash concentrates, as predicted by laboratory testing and confirmed at a growing number of mill sites.

INTRODUCTION

The GRG test was designed to characterize *G*ravity *R*ecoverable *G*old (GRG) ten years ago (Woodcock and Laplante, 1993; Laplante et al, 2000), in response to the need to predict how much gold could be recovered from the main circulating load of grinding circuits using centrifuge concentration. The amount of GRG is not itself a prediction of gravity recovery: the performance of a gravity circuit nested in a circulating load also depends on the type and size of unit used, how much of the circulating load is treated, and how many times GRG is recycled and presented to the recovery circuit. The GRG test was first used in a simulator to predict gravity recovery (Laplante et al, 1995), and indeed most of the early tests targeted ores or prospective ores for which gravity recovery was an obvious match. As the test became more accepted, more and more samples returned a verdict that precluded the use of gravity recovery, or made it marginal. Typically, such ores are either copper-gold or base metal ores in which the GRG content is often fine (largely below 105 μm) and ranges from 8 to 33%. Extensive simulation and plant sampling tests, either published (Laplante et al, 1997) or proprietary, show that full scale gravity recovery for these applications is generally below 10%, and can be as low as 2%. Not in all cases are such low recoveries economically unjustifiable, since there is documented evidence (Darnton et al, 1992) that a significant proportion of the gold recovered, at least in the case of base metal ores, would not have reported to the copper or zinc concentrate and received NSR credits.

As the McGill team investigated more and more gravity circuits, it soon encountered flash flotation cells, at Lucien Béliveau, Chimo, MSV and Louvicourt Mine (Putz et al, 1993; Duchesne et al, 2001). One fact soon became very clear: flash flotation was extremely efficient in dropping the circulating load of GRG at fine range, typically below 106 μm (selective Cu-Zn flotation) to below 212 μm (bulk sulphide flotation). Figure 1 (Putz et al, 1993)) illustrates the drop of GRG content at finer sizes at Lucien Béliveau, where a bulk pyrite concentrate was floated for cyanidation at Yvan Vézina. Note that the GRG shows a hump that is caused by the flotation of GRG starting at 212 μm and pyrite starting at approximately 106 μm.

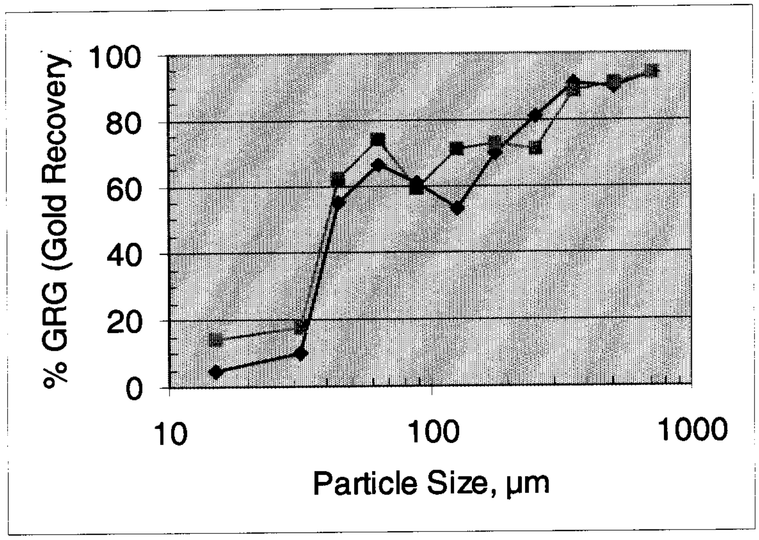

Figure 1. GRG Content as a Function of Particle Size at Lucien Béliveau (Putz et al, 1993; Putz, 1995)

The Louvicourt presentation on Flash Flotation at the 2001 CMP was a reminder to the Canadian mineral processing community that flash flotation could present a significant benefit, but this was hardly the first time this had been noticed. The early references are difficult to obtain, as they appear not to have been formal publications, and are referenced rather vaguely. Bourke (1995) pegs 1982 as the year the first Outokumpu SK-80 was commissioned, at the Hammaslahti mill. A seminal paper by Kallionen and Niitti appears to lay the foundations for the rationale of flash flotation in grinding circuits. In essence, they claim that cyclone partition curves for base and precious metals provide size distributions that are better suited for flotation at the cyclone underflow, rather than the cyclone overflow. Koivistoinen and Miettunen have reported that flash flotation could increase gold recovery by as much as 10%, more than ten years ago. Sandstrom and Jonsson (1988) reported, for short trials at the Aitik Mine, increases in gold recovery averaging 12%. Benefits also extend to platinum group elements, present either as liberated species or in sulphide minerals (Thurman, 1994). The practice has been resisted by some on the basis of potential circuit disturbances in grinding circuits, but even if this problem was ever significant, today's better control systems make it moot. Some mines have installed then removed flash flotation (e.g. OK Tedi), but it is unclear whether or not changes in the amount of GRG were responsible for changes in the impact of flash flotation. Flash flotation must be considered a serious contender, especially when (a) the GRG content is significant but does not justify a gravity circuit, (b) flotation is already the main recovery option, and (c) the GRG content is high but fine. The practice is already the standard approach of Newcrest, first championed at Telfer (Sherman and Engelhart, 1993), implemented Cadia (Dunne et al, 1999), and planned for the Telfer extensions.

Both flash flotation and gravity recovery can then be thought of additional recovery steps that can only be justified if the amount of gold recovered is above a certain cut-off grade. The ability of flash flotation to process more tonnes (with very large units SK1200, ~52m^3), recover fine gold more effectively than gravity recovery and recover gold in gold carriers gives it a lower cut-off grade than batch centrifuge concentrators (BCCs).

If flash flotation is indeed indicated, the following questions can be raised: (a) should flash flotation or gravity, or both, be used, (b) if both flash flotation and gravity recovery are used, how should they be configured, and (c) can the GRG test and modeling methodologies assist is circuit selection and performance prediction? This contribution addresses the three questions and presents actual data illustrating some of the principles expounded here, most of it based on Newcrest's Cadia mill in New South Wales.

PROCESS OPTIONS

Primary Loop: Flash or Gravity? Both?

When the grinding circuit has two circulating loads, the authors advocate tapping the primary loop for gold recovery, either at the ball mill feed or cyclone underflow, rather than the secondary load. In all McGill surveys of plants that included primary and secondary classification, the primary cyclone underflow had a better potential for gravity recovery than the secondary cyclone underflow (Banisi et al, 1991; Woodcock, 1994; Xiao, 1998).

For sulphidic base metal ores, flash flotation should be tested very seriously, because of the relatively low cost of installing a flotation unit compared to the potential benefits of increased NSR and lower reagent costs. For brownfield applications, the circulating load of gold can be an indicator of potential flash flotation performance (the higher the load the higher the potential gold recovery). There are indications that the benefits of flash flotation depend on the amount of GRG: for example, flash flotation at Macreas was not thought to be beneficial because of the low GRG content (most gold is present as gold carriers (Hollis el al , 1993; Bourke, 1995).

For gold ores that do not contain potentially cyanicidal base metal species, the use of flash flotation is not as common, and only makes sense if sulphide concentration is advisable. This is normally used in four cases:

- Pre-concentration of the cyanidation feed (flotation tailing to be discarded)
- Pre-concentration for subsequent oxidation (roasting, autoclaving, bioleaching) for refractory ores (flotation tailing to be cyanided)
- Pre-concentration for direct intensive cyanidation
- Recovery of gold-bearers and incompletely leached gold particles from a cyanidation tailing for finer grinding and intensive cyanidation.

Of the four options, the third option is relatively less common, and can be used in the case of high preg-robbing ores (Lewis, 1999 and 2000), in which case gravity rather than flotation should be used. When the third option is used for concentrating sulphides for finer grinding before cyanidation, flotation is an attractive option. For the fourth option, sulphides-carrier recovery by gravity is to be preferred over flotation –e.g. New Celebration (Delahey el al, 1992).

With the second option, the main benefit of flash flotation is an increased recovery of the gold carrier (sulfide) by limiting over-grinding. This translates into a higher gold recovery. Without flash flotation over-ground gold bearing sulfides in the cyclone overflow are not recovered as efficiently in downstream flotation. Even when the flotation tailing is cyanided, the refractory nature of the gold present normally yields poor cyanide recoveries, typically much lower than what is achieved with the oxidized stream. Flash flotation may also assist in the production of a throwaway tailing from a downstream conventional flotation circuit, but this is unlikely in most cases.

Notwithstanding the number of cases that are discussed in the above paragraphs, the use of flotation in the absence of economically recoverable base metals is the exception rather than the norm. Political pressure to ban or reduce the use of cyanide may modify industrial practice in some countries or states and make flotation more attractive, in which case flash flotation would see more applications. Of the alternate leachants, of particular interest is the thiosulphate route, which may be easier to apply and thus more attractive on higher-grade feeds –i.e. gravity or flash flotation concentrates.

The use of both gravity recovery and flotation from the primary circulating load is restricted to very special cases where the attractiveness of recovering a smeltable precious metal concentrate (either to facilitate smelter settlements or maximize NSR) and maximizing metallurgical recovery coincide. It should understood that the two recovery methods will tap from the same circulating load, gravity recovery being the dominant recovery method above 212 μm and flotation below. Under such circumstances, gravity recovery should target mostly coarse gold, and the use of a unit that can treat the full cyclone underflow without excessive dilution, even at the expense of fine gold recovery (e.g. Gekko's IPJ, Gray, 1997), is particularly appropriate.

At Macreas, the original flotation circuit incorporated column cells. These were unable to cope with the froth load imposed in floating both sulfide and carbonaceous material and consequently overall sulfide, and therefore gold, recovery decreased. Flash flotation of the carbonaceous components was implemented, which made it possible not only to improve downstream sulphides recovery, but also minimize the surface area of the carbonaceous material and hence its preg-robbing capabilities.

Table 1 summarizes the process options in the primary grinding loop.

Table 1. Flash Flotation and Gravity Recovery in the Primary Loop: Process Options

Option	Rationale	Mills
Gravity alone	Coarse gold recovery ahead of cyanidation GRG recovery ahead of base metal flotation to increase NSR and overall gold recovery	Most gold mills Camchib, Osborne, Bulyanhulu
Flash flotation alone	Increase base and precious metal recovery ahead of conventional flotation	Louvicourt, Cadia, Lucien Béliveau
Gravity and flash flotation	Base and precious metal recovery in the presence of coarse GRG	MSV, Chimo, Eskay Ck., Ridgeway (planned)

Interfacing Flash Flotation and Gravity Recovery

When flash flotation and gravity recovery are both used, how should they interface?

In the first section, the use of gravity to recover coarse gold and flash flotation to recover fine gold and sulphides is discussed. The most frequent joint application of the two recovery methods is the use of gravity recovery to recover GRG from the flash flotation concentrate. The incentive for such treatment usually lies in the increased NSR obtained with very high-grade gold concentrates. The overall evaluation of the benefit of gravity in this case should include the potential lower payment of gold left in the flotation concentrate, because of its lower grade.

A second, often overlooked, incentive lies in the minimization of gold losses from the flash flotation concentrate, when further upgrading is required. The two objectives (maximizing NSR and flotation recovery) are not always easily pursued. Figure 2 shows two flowsheets, each aimed at maximizing one of the two objectives. The first flowsheet redirects the gold room tailing to the grinding circuit for additional GRG liberation or gravity recovery. Note that "coarse" gold losses are more likely to occur, because flotation cleaners, with their typically deep froths, are not designed to recover coarse gold. If the flash concentrate requires cleaning, it makes more sense to direct the flash flotation concentrate to a dedicated cleaner stage, rather than the overall cleaner treating the conventional rougher concentrate. This is shown in the second flowsheet of Figure 2. Such circuits are small thus inexpensive and often treat very high value products whose grades are much higher than the rougher flotation concentrates produced by conventional flotation. Thus combining these two very dissimilar products makes little sense. Similarly, because the gold grade of the gold room tailing is either equal to or greater than that of the final flotation concentrate, it is added to it, to minimize gold losses. At

Cadia, the tailing of the Falcon SB5200[1] that treats the flash flotation concentrate is directed to a dedicated cleaner circuit that achieves a recovery of 98%. The gold room tailing is added to the final copper concentrate, after scavenging with a small Falcon SB unit.

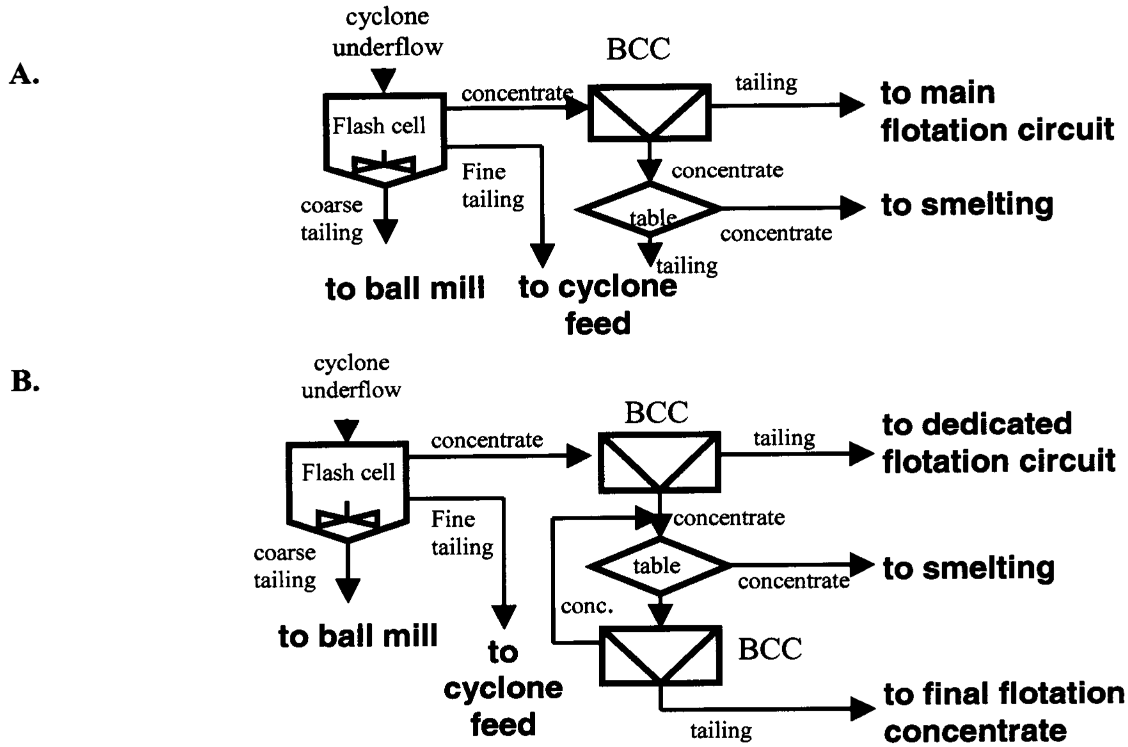

Figure 2. Two Proposed Flowsheets (A maximizes gravity recovery; B maximizes total recovery)

The use of a regrind circuit treating a high-throughput, relatively coarse rougher concentrate stream (e.g. Alumbrera, Keran el al, 1998) is becoming common for low-grade gold-copper ores. When such a circuit is used, gravity recovery from the circulating load of the regrind circuit is very attractive, but it should be pursued with high-Gs units, typically 150 Gs or more, owing to the very fine size distribution of the GRG.

The potential user must understand the two hurdles to overcome when processing flash flotation concentrates with batch centrifuge concentrators (BCCs). Firstly, flash flotation concentrates have a high sulphide content, which is the "gangue" from which GRG must be recovered. These separations are inherently more difficult than recovery from a silicate gangue. Secondly, and maybe more importantly, whereas recovery from the primary circuit is a multi-pass application, flash flotation concentrate are usually

[1] The new Falcon notation is based on surface rather than diameter. The SB 5200 was originally identified as SB38, for its diameter, 38 inches.

processed only once by BCCs. This can lower gravity recovery very significantly, especially for GRG finer than 37 μm.

At the Cadia mill, gravity recoveries of 15 to 18% are achieved with a Falcon SB4000 and gold room, compared to a GRG content of 68%. The SB4000 recovers approximately 50% of the gold in the flash flotation concentrate (which contains 30 to 40% of the gold in the ore). The low overall gravity recovery is much more a reflection of the low flash flotation recovery and the single-pass nature of the application than any failings of the Falcon SB. The low flash flotation recovery is largely due to the coarse grinding size, a P_{80} of 200 to 220 μm, which fails to keep the finer GRG in the circulating load. This will be analyzed later.

At the Mourro do Ourro plant, high gravity recoveries (over 50%) were achieved by treating the flash concentrate of an oxide ore with three BCCs in series (to minimize the drawback of the lack of circulating load). The BCC concentrate was then processed on a shaking table, although large pans were later used, providing some 10% more recovery (Suttill, 1990; Tondo, 1996). Rare are the applications that can justify such a recovery effort. When the oxide ore was mined out, the gravity circuit was shut down because the sulphide ore that is now being treated has a lower content of finer GRG present is a higher s.g. gangue (i.e. the flash flotation concentrate).

The GRG Test, GRG-Based Modeling and Flash Flotation

The rationale for using the GRG test when predicting gold gravity recovery and/or analyzing the behavior of gold in grinding circuits with flash flotation is the large difference between the behavior of GRG and non-GRG in grinding circuits. Non-GRG is relatively fine gold (<< 10-15 μm) in gold carriers, typically sulphides, or in the low-density gangue, typically silicates. Gold carriers are considered here to be particles that have a density that is high enough to allow gravity separation from the low-density gangue, which can be performed with spirals, Riechert Cones or continuous centrifuge units (the Geologics Kelsey jig is the most promising unit for this duty). Typically, the retention time of non-GRG in grinding circuits is of the order of magnitude of that of its host carrier, and is largely a function of its partition curve, which is highly s.g. dependent. The partition curve of GRG, on account of the s.g. of gold, is very different from that of sulphides –i.e. even very fine GRG will report to the cyclone underflow with a probability of 70 to 98%. Figure 3 shows the partition curve of GRG in the B-circuit of the Golden Giant mill, which produces in a single classification stage a product 90% finer than 75 μm. Even below 25 μm, GRG massively reports to the cyclone underflow. Notice that the gangue partition curve has a rather unusual shape, which can be interpreted as the partition curve of non-sulphide gangue at coarse size and an important contribution from the partition curve of sulphides at fine size. A discussion of this transition can be found in Laplante and Finch (1984).

Very fine GRG also grinds slowly (Banisi et al, 1991). It follows that GRG is presented to the flash unit a much higher number of times before it either floats or in ground into very fine GRG or non-GRG that can report to the cyclone overflow. Gold in gold-carriers benefits from a slightly finer classification than gold in silicates, but is present in particles that grind with similar kinetics and cannot therefore be expected to benefit from the high circulating loads of GRG.

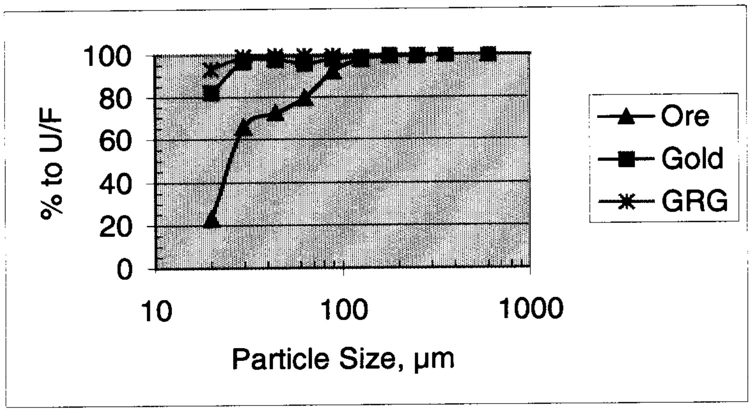

Figure 3. Partition Curves of Ore, Gold and GRG in the B Circuit of Golden Giant

The behavior of GRG is tied to its size distribution, a very important variable in predicting gold recovery by gravity that is generated from the GRG test. The importance of the GRG size distribution in gravity recovery can be linked to the inability of virtually all gravity separators, including BCCs, to recover fine GRG as effectively as coarse GRG when operated at high specific feed rates. The GRG size distribution does not affect flash flotation performance as significantly, as fine GRG can be recovered very effectively by flotation.

GRG recovery is significantly affected by the fineness of grind, much more via the partition curve of GRG than its actual liberation. This is expected to apply also to flash flotation.

The modeling of the grinding and classification of GRG can be tied to the fineness of grind of the grinding circuit, whether design or measured (Laplante et al, 2001). Figure 4 (Xiao, 2001) compares predicted and measured gold recoveries based in part of this approach. The reasonable fit suggests that either the methodology accounts for the effect of fineness of grind reasonably well, or that the effect of fineness of grind is minor. An important conclusion of the simulation work is the finding that GRG recovery is proportional to the logarithm (base 10 or natural) of the recovery effort. This finding has many implications, such as the rapidly diminishing return of trying to recover more (this will be illustrated with the Cadia case study) or the relatively small importance of estimating the recovery effort with high precision. The approach presented at last year's CMP will be adapted to GRG recovery by flash flotation at Cadia.

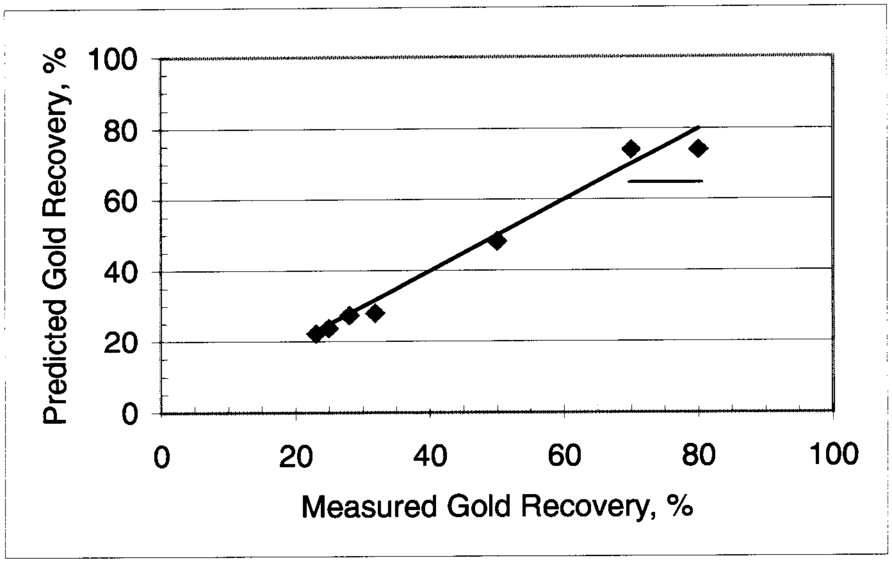

Figure 4. Comparing Predicted and Measuring Gravity Recovery at Various Sites (from Xiao, 2001)

THE CADIA CASE STUDY

Background

The Cadia concentrator, situated near the town of Orange in New South Wales Australia, was designed to treat 17Mtpa of a copper-gold ore. The average gold and copper grades of the deposit are 0.73g/t and 0.17% respectively. The circuit consists of a single open circuit SAG mill with two parallel ball mills in closed circuit with classification cyclones. A portion of each cyclone underflow is treated in a flash flotation cell. The concentrate from this passes through a centrifugal gravity separator to remove free gold. The tailings from the gravity separator report to "coarse " cleaner flotation cells. The concentrates from these go directly to final copper concentrate. The tailings are pumped to the regrind mill that is contained in the conventional flotation cleaning circuit. The ball mill cyclone overflows feed two parallel rougher-scavenger flotation banks. The concentrates are combined; a portion being reground, and then cleaned and re-cleaned in a conventional cleaning circuit to produce a final copper concentrate. The combined final concentrate is filtered and then sent to a smelter. The concentrate from the gravity separator is cleaned to produce a product for direct smelting. The doré is sent to a gold refiner.

Design

The requirement to treat large tonnages, because of the low grade content of the ore, and the necessity to use the largest available equipment, to reduce both capital and operating costs, meant that a thorough and meticulous approach was implemented to predict flash flotation performance. The choice of flash flotation rather than gravity recovery was not due to the absence or low content of GRG, but on its relatively fine size distribution and the absence at the time of a higher capacity BCC capable of operating at higher Gs. Figure 5 shows that all three samples originally tested for GRG content (1994 a, b and c) had varying degrees of generally fine GRG. A fourth sample, recently tested, shows that GRG content evolved slightly as mining progressed since 1998, with a slightly coarser (>150 μm) GRG content for a sample recently tested (curve 2001), most of which is comprised of liberated or near-liberated gold particles. Piloting was also performed and flash flotation concentrate samples were tested for GRG content, with a single pass in Falcon SB40 and Knelson MD3 units. Both units proved capable of recovering approximately the same amount of gold, although the Knelson generally performed better at intermediate particle size and the SB in the finer size range (Figure 6).

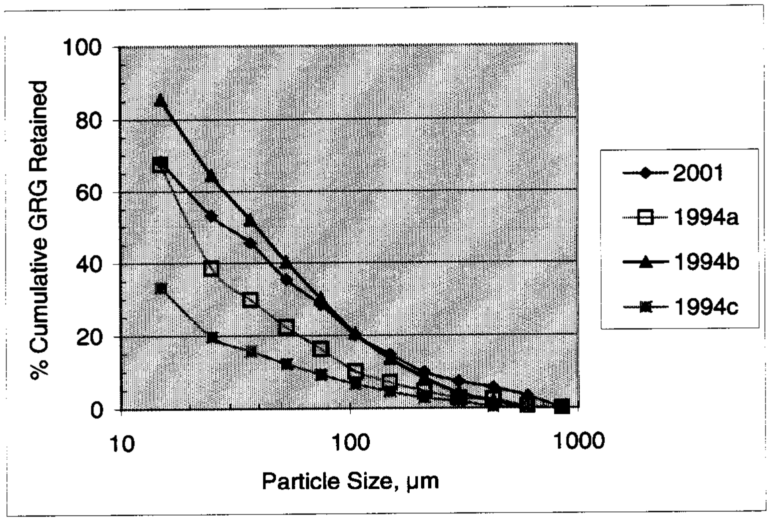

Figure 5. Cumulative Retained Gravity Recoverable Content in Four Cadia Samples

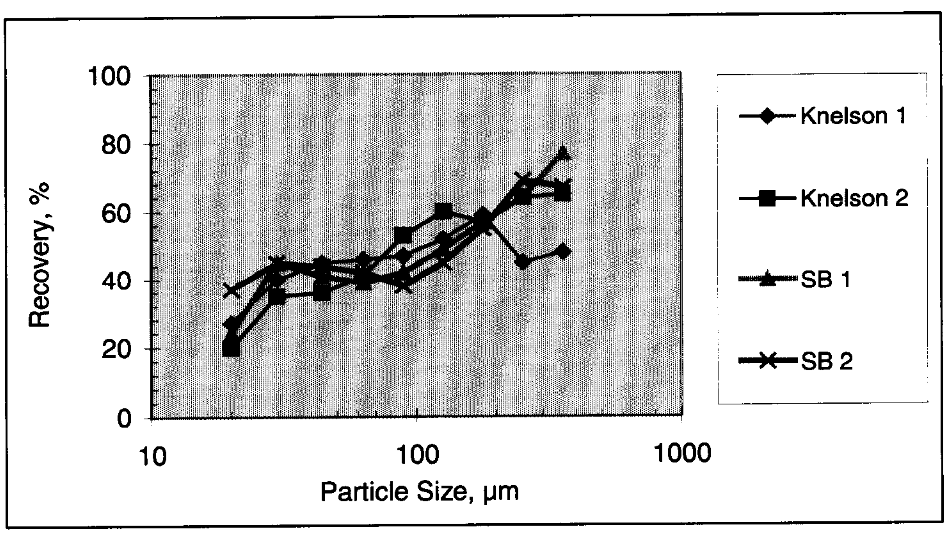

Figure 6. Response of Flash Flotation Concentrates to BCC Concentration with Falcon SB40 and Knelson MD3 Units (1: lower feed rate; 2: higher feed rate)

Further testing involved BCC concentrate samples from Macreas and Morro de Ouro, where the degree of liberation and size distribution of gold were also determined. The objective was to compare bench scale concentrates from Cadia to actual concentrates from Macreas and Morro de Ouro, to predict what performance could be achieved at Cadia. Table 2 shows the size distribution of the gold in the flotation concentrates. These samples were carefully hand-panned and examined at Amtel to determine their size distribution and degree of liberation. Results were quite different from Table 2. Figure 7 shows the size distribution of the gold thus recovered, and highlights that the Macreas gold size distribution approaches most that of Cadia. On the basis on these results, it was decided to proceed implement the Falcon-based gravity circuit.

Table 2 Comparing the Size Distribution of Gold in the Flash Concentrates of Morro do Ouro, Macreas and Cadia

Size, µm	Morro Oxide	Morro Sulphide	Macreas	Cadia
300	2.6	-	2.5	-
212	9.7	-	10.9	0.9
150	17.1	0.1	22.2	3.8
106	13.5	1.1	20.1	10.8
75	19.8	3.7	16.4	16.0
53	14.4	22.0	9.9	15.9
37	13.5	62.0	6.8	16.7
25	1.8	2.0	4.6	12.7
-25	7.7	9.1	6.5	23.4

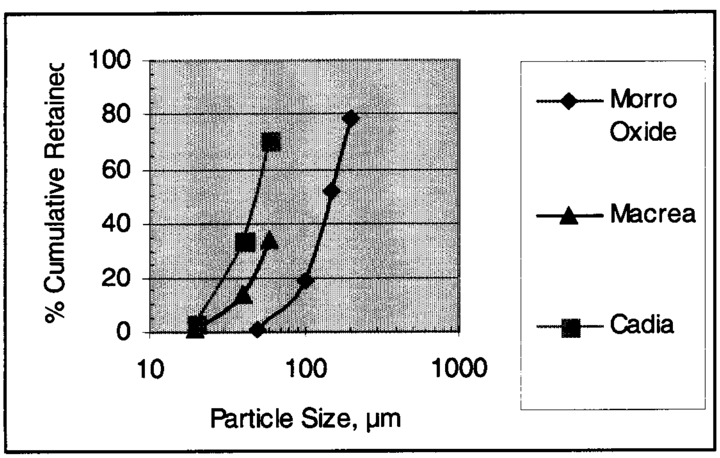

Figure 7. Size Distribution of the Panned Gold in the Morro do Ouro Oxide, Macrea and Cadia Ores

In June of 1999 a tertiary crushed development ore from the Ridgeway deposit, a high grade underground deposit close to the Cadia mine, was included in the feed stream of the Cadia SAG mill. The effect of this was to coarsen the ball mill cyclone overflow from a P_{80} at that time of 180 µm to a P_{80} of around 220 µm.

Recent Results

Unlike all other flash flotation units surveyed by members of the McGill University research group, the input and outputs of the Cadia flotation cell unit can all be sampled and a full mass balance of the unit can be reliably established. Six recent surveys of the flash flotation circuit yielded the size-by-size gold recoveries shown in Figure 8. Overall gold recovery from the flash varies between 35 and 40%. The Falcon SB5200 recovers approximately 50% of the gold present in the flash flotation concentrate, irrespective of its grade. The Falcon concentrate is further cleaned on GT1000 and GT250 Gemeni tables in series. The table tailing is scavenged in a Falcon SB250. The Falcon tailing is combined to the final flotation concentrate, contributing approximately 7 to 8 g/t to its overall grade.

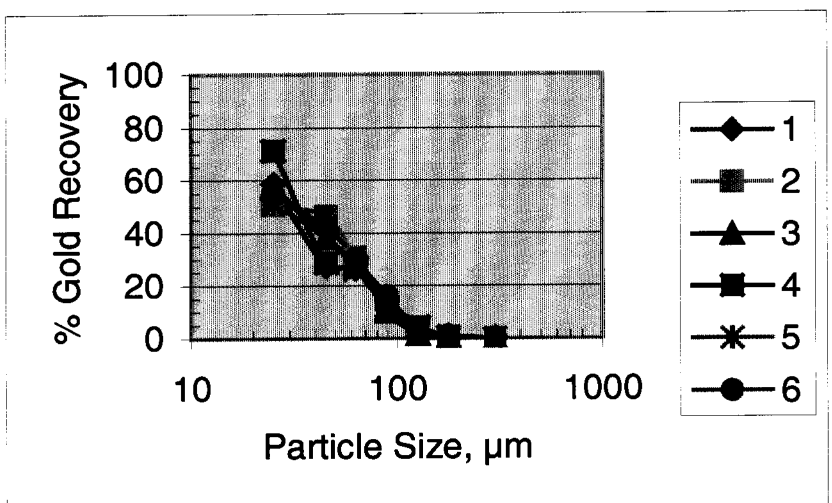

Figure 8. Flash Flotation Gold Recovery as a Function of Particle Size

The flash cell itself also acts as a classifier, and Figure 9 shows how solids (ore), gold and copper split between the fine and coarse tailing streams. The fine tailing stream can be directed to the cyclone feed, which significantly improves classification performance. In essence, cyclone classification can be tuned to the desired cut-size without the constraint of a low by-pass, since the by-passed fines, which are either floated in the flash cell or report to the fine tailing, do not occupy valuable space in the ball mill.

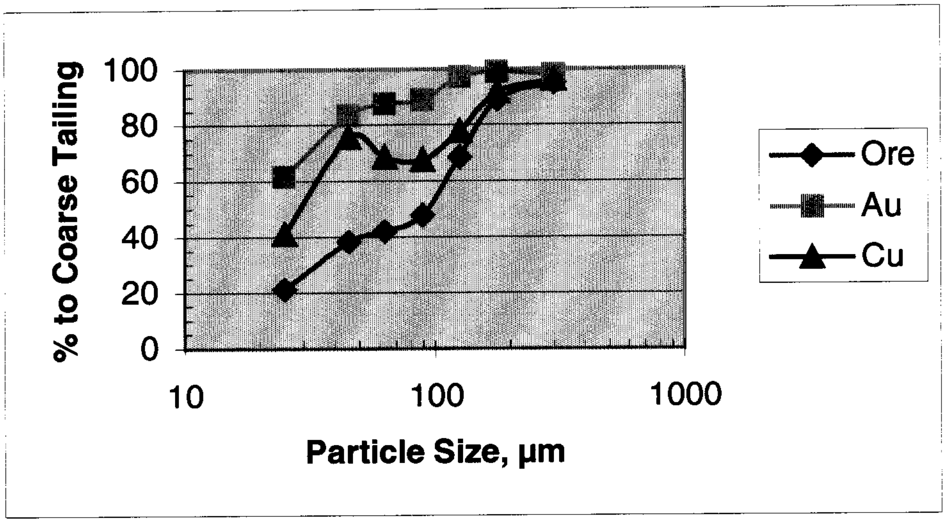

Figure 9. Partition Curve of the Flash Cell

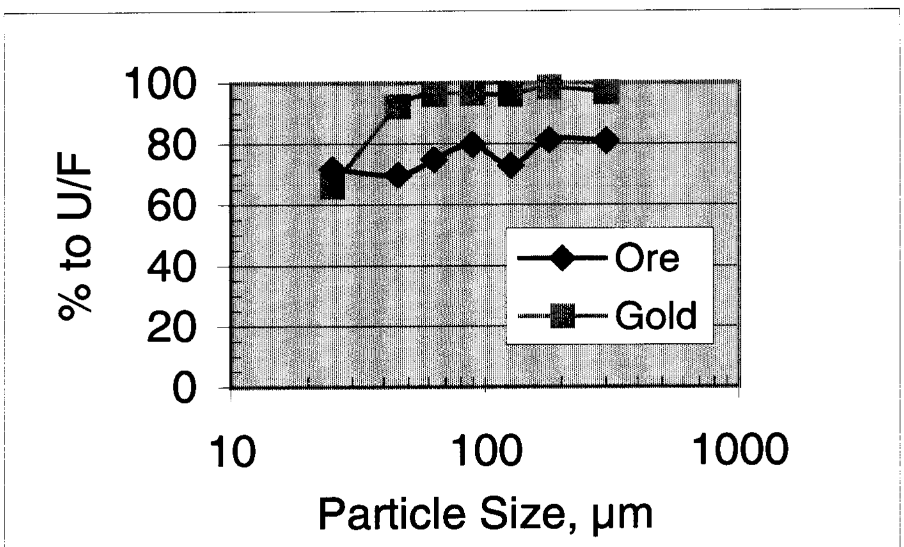

Figure 10 Partition Curve of the Primary Cyclones

Figure 10 shows the partition curve of the primary cyclones. The full "S" shape of the curve is not visible, because the coarsest size class, the plus 212 µm fraction, was chosen to describe flotation rather than classification. The by-pass fraction appears to be rather high, but this problem is mitigated by the classifying action of the flash cell illustrated in Figure 9.

Simulation

If the recoveries of Figure 6 are assumed to hold for GRG rather than total gold, it becomes possible to simulate GRG recovery, using the GRG curve corresponding to the latest determination of GRG content in the Cadia ore (Figure 4, curve d). Additional information required includes the parameters τ and $R_{-25\mu m}$, corresponding respectively to the dimensionless grinding time in the ball mill and the % to cyclone underflow of the minus 25 µm GRG fraction. This last parameter is normally extracted from the fineness of grind, but it can be directly estimated from Figure 10, if GRG is assumed to behave like total gold. The parameter τ can be estimated from fineness of grind (%-75 µm) and the circulating load of the grinding circuit, which is 325% (300-350%) at Cadia.

Recovery from the cyclone underflow can be described with the equation:

$$\underline{D} = PR * [1-BC * (I-PR)]^{-1} * C * \underline{F}$$

where $\underline{D}$	:	Recovery vector
P	:	Preconcentration matrix
R	:	Recovery matrix
B	:	Breakage matrix
C	:	Classification matrix
$\underline{F}$	:	Vector representing the size-by-size GRG content of the ore

More details were presented at least year's Annual CMP Meeting (Laplante et al, 2001). The preconcentration matrix is a diagonal matrix of 0.5, since 50% of the cyclone underflow is directed to the flash cell. The recovery matrix is also diagonal, and represents the data of Figure 8. Estimation of the breakage matrix was presented at last year's CMP meeting. The classification matrix represents the data of Figure 10, and $\underline{F}$ represents the data of Figure 5 (curve 2001).

Simulation with the above data yields a GRG recovery of 32% of the gold in the ore. In practice, flash flotation recovery is 35 to 40% of the gold in the ore. The two numbers are in good agreement, since not all of the gold in the flash flotation concentrate is gravity recoverable. In fact, it can be assumed that all of the non-gravity recoverable gold (non-GRG) is finer than 25 µm. If the non-GRG is lumped with the –25 µm fraction (since it can presumably be floated), the simulated recovery equals 40.5%, which sits at the top of the range of observed recoveries. More importantly, Figure 11 shows that the gold distribution thus modeled fits the average gold distribution of the six sampling surveys very closely.

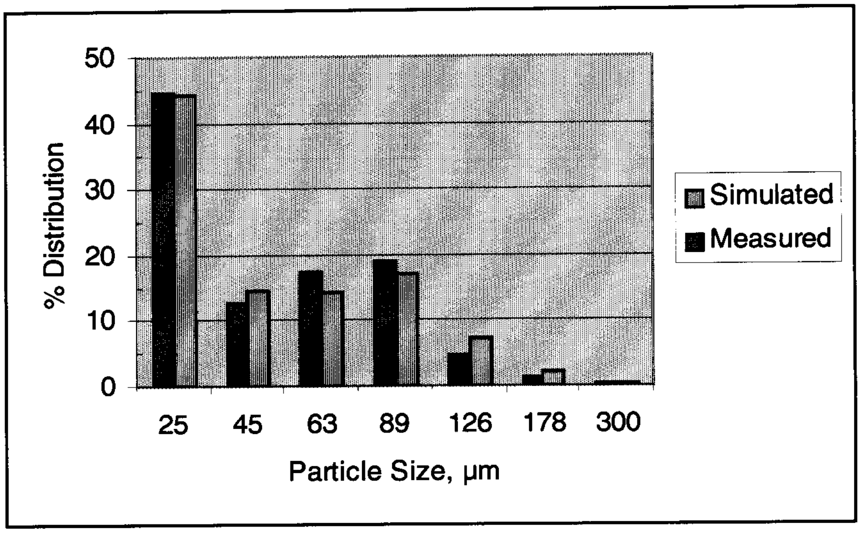

Figure 11. Comparing the Modeled and Measured Gold Distribution in the Flash Concentrate

Having determined that the model can predict performance reliably, the next step is to examine three different scenarios. The first is the use of a gravity device rather than flash flotation. Treating 25% of the circulating load with a centrifuge that recovers from 10% of the –25 μm GRG to 90% of the +600 μm GRG yields a recovery of 26% of the total gold, which is less than what is presently achieved by flash flotation. Higher recoveries could be achieved if a finer grind was sought, but economics clearly dictate, at the low head grade, a high throughput that can only be achieved at coarser grind.

The second "what if" scenario is to install the flash cell at the mill discharge. Recovery then jumps to 52.4%, the main contribution coming from non-GRG that is finer than 25 μm. Still, a healthy 5% increase in GRG recovery is noticed. Whilst installing the flash cell at the discharge of the ball mill is not practical, an equivalent and much easier approach may be to direct the concentrate of the first conventional rougher cells to gravity recovery, along with the flash concentrate. The amount of GRG in the first cell of the conventional flotation circuit should be measured to evaluate the feasibility of this option.

The third scenario is to install a second flash cell to treat the full cyclone underflow. Total gold recovery then increases to 54.5% (from 40.5%), and GRG recovery increases to 41.2% (from 32.1%).

CONCLUSIONS

In this paper, the documented impact of flash flotation on precious metals recovery was examined. The main findings were

- Increases in precious metals recoveries of 3 to 12% have been reported
- Benefits extend to base metals and platinum group elements

- Good recovery data are difficult to obtain because of the lack of sampling point at the coarse tailing discharge.

Linking flash flotation and gravity recovery was discussed. It was concluded that

- In most applications and in the absence of coarse GRG, the logical flowsheet was to use flash flotation in the primary grinding loop and treat the flash concentrate with a BCC
- The flash concentrate or BCC tailing should be further upgraded in its own circuit, given its very high GRG content. Very high cleaner recoveries are achieved at Cadia this way.

The Cadia case study was used to demonstrate that the GRG test could be used to model the flotation of GRG. It was found that

- The flash cell can be used as a classifier, in particular to mitigate a high by-pass fraction in the primary cyclones
- The BCC performance (a Falcon SB4000) could be predicted accurately from bench scale work
- The model predicted well the amount and size distribution of the gold in the concentrate, when all of the non-GRG is lumped with the minus 25 µm GRG
- GRG recovery by flash flotation was less than the GRG content on account of the coarse classification cut-size, but higher than what would have been achieved with a BCC
- A significant proportion of the fine GRG reported to the cyclone overflow, which may make the concentrate of the first cells of the main flotation circuit a good candidate for gravity recovery
- Installing a second flash cell to treat the full cyclone underflow is probably warranted.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of José Dioses of the Cadia Hill Gold Mine and Peter Bourke of Outokumpu. Thanks also to Newcrest Mining Limited for permission to use the data from the Cadia Hill Gold Mine.

REFERENCES

Banisi, S., A.R. Laplante and J. Marois, "A Study of the Behaviour of Gold in Industrial and Laboratory Grinding", CIM Bull., Nov. 1991, pp. 72-78

Bourke, P., Flash flotation in the gold industry, Randol Gold Forum, Perth, March, 1995

Darnton, B., S. Lloyd and M.A. Antonioli, Gravity concentration: research, design and circuit performance at Montana Tunnels, Randol Gold Forum, Vancouver, March 1992, pp. 137-143.

Delahey, G., Martins, V. and R Dunne, Plant practice at the New Celebration Gold Mine, International Conference on Extractive Metallurgy of gold and Base Metals, AusIMM, Kalgoorlie, 1992, pp 95-101

Duchesne, S, J Cayouette, B. Dallaire, Installation of flash flotation units at the Louvicourt Concentrator, Proc. of 33rd Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 2001, Paper 21, pp. 285-302.

Dunne, R., Chittenden, R., Lane, G. and S Morrell, The Cadia gold copper project-exploration to start up, SME Annual Meeting, Denver, Colorado, 1999

Gray, A.H., InLine pressure jig,- an exciting low cost technology with significant operational benefits in gravity separation of minerals, Proc. Of the AusIMM Ann. Conf., Ballarat, March 1997

Hollis, K M., Allen, P J. and M D Catzow, Gold ore treatment by Macreas Mining Company, Macraes Flat, New Zealand, AusIMM Monograph No 19, 1993, pp 989-993

Kallionen, J. and T. Niitti, The basis of coarse flotation kinetics and practical realization of classifier sands flotation, source unknown

Keran, V P., F. Zumwalt, and J. Palmes, Designing the Minera Alumbrera concentrator circuit, Mining Engineering, Sept. 1988, pp. 31-37

Koivistoinen, P. and J. Miettunen, The role of the concentrator in maximizing the economic result of a mining operation, source unknown

Lane, G., Fleay, J. and A Marin, Examining the effects of comminution on downstream Flotation, Crushing and Grinding 99, IIR Conference, Perth, March, 1999

Laplante, A.R., F. Woodcock and M. Noaparast, Predicting gravity separation gold recovery, Minerals and Metallurgical Processing J., May 1995, pp. 74-79

Laplante, A.R., B. Zhang, L. Huang, J. Ling, P. Cousin and L. Racine, 'Difficult Gold Gravity Separations', Proc. of 29th Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 1997, Paper 31, pp. 421-434

Laplante, A.R., F. Woodcock and L. Huang, Laboratory procedure to characterize gravity-recoverable gold, Trans. of SME, Vol. 308(2000), p. 53-59

Lewis, G., Increased recovery from preg-robbing gold ore at Penjom Gold Mine, Randol Gold Forum, Denver, May 1999, pp.105-108

Lewis, G., The Penjom process, Randol Gold Forum, Vancouver, April 2000, pp.163-168.

Putz, A., A.R. Laplante and G. Ladouceur, Evaluation of a Gravity Circuit in a Canadian Gold Operation, Randol Gold Forum, Beaver Creek, September 1993. pp. 145-149

Putz, A., A Survey of Canadian Gold Gravity Circuits, M.Eng. Thesis, McGill University, 1994, 230 pp.

Sandstrom, E. and H. Jonsson, Unit flotation practice at Boliden Mineral AB, XIV Intern. Min. Proc. Cong., 1988

Sherman, M. and D Engelhart, Copper gold ore treatment at Telfer Mine, Telfer, WA , AusIMM, Monograph No 19, 1993, pp 685-689

Suttill, K R., Morro de Ouro- Brazil's hill of gold, E/MJ, June, 1990

Tondo, L., Private communication, 1996

Woodcock, F. and A.R. Laplante, A Laboratory Method for Determining the Amount of Gravity Recoverable Gold, Randol Gold Forum, Beaver Creek, September 1993. pp. 151-155

Woodcock, F., Prediction of Gold Gravity Recovery , M.Eng. Thesis, McGill University, 1994, 128 pp.

Xiao, J., An Evaluation of the SuperBowl, M.Eng. Thesis, McGill University, 1998, 131 pp.