

## **EXPLORING HPGR TECHNOLOGY FOR HEAP LEACHING OF FRESH ROCK GOLD ORES**

Brian M<sup>c</sup>Nab  
Senior Metallurgist - Comminution  
Orway Mineral Consultants  
brianm@orway.com.au

**IIR CRUSHING & GRINDING CONFERENCE 2006**  
29 – 30 March 2006 Townsville, Qld

### **ABSTRACT**

This paper discusses the concept of applying HPGR technology to the preparation of low grade gold ores for heap leaching. Examples of recent testwork results from four Western Australian projects are discussed with key issues for the flowsheet development team identified.

Understanding the leach extraction and therefore the lowest cut-off grade that can be fed to a HPGR heap leach circuit is obviously important. Establishment of the upper and lower boundary and variability of the gold grade and recovery window defines the feed limitations. Across a resource, both measures are crucial to project economics. Characteristics that promote the application of HPGR prepared Heap Leach processing for large tonnage projects are presented in the paper. Of note is the potential dual use of the crushing circuit for both the main CIL/P plant and the heap leach.

HPGR has been shown to influence the extraction and kinetics of leaching low grade gold ores. A very significant increase in gold extraction is typically returned for HPGR prepared -2 mm feed, compared to cone crushed material in amenable ores. Directly comparing leach extraction performance from machines that inherently produce differing PSDs can however be misleading. Both the increased fines production from the HPGR and the influence of micro-fracturing contribute to the improved leach extraction. Indications suggest a 10 to 11% additional gold leach extraction due to the HPGR micro-fracturing effect, together with gains from increased amounts of fines in an HPGR prepared feed of the same topsize.

The HPGR pressing force has been found to be a sensitive operational variable with respect to leach extraction and operational costs. Benefits include better liberation and costs include the need for agglomeration with cement to facilitate percolation through the heap. Scale-up issues are also discussed.

The accuracy of testwork sampling and analysis for process design is as critical as that used in the resource estimation.

## **1.0 INTRODUCTION**

In recent years significant increases in mineral commodity prices, energy costs, capital and operating costs have developed a new playing field on which to evaluate mineral processing options. Of specific interest is the window of opportunity that has opened for processing of low-grade fresh rock ores. Historically, for free milling hard rock gold operations, particularly in Western Australia (WA), a CIL/P circuit was designed at a throughput in accordance with the optimal project economics. The size of the circuit would generally dictate the operating cost and as a consequence define a lower cut-off limit for the definition of mill feed. Ore below the cut-off grade was generally not evaluated and as a consequence directed to waste or mineralised waste stockpiles.

With today's commodity prices, assessment of open cut mining shells using a \$AUD 700 - 800/oz gold price can be justified. This compares with \$AUD 400 -550/oz commonly used in the late nineties and earlier this century. As a consequence open pit operations can be feasible to greater depths and significantly larger volumes of low-grade fresh rock ore are often drawn into the mining envelope. As such, the focus on assessing the potential economic recovery from these fresh rock low-grade gold ores is increasing.

Esna-Ashari & Kellerwessel (1988), Patzelt et al (1996) and Baum (1997) have reported on the liberation benefits of HPGR for gold and copper ores. Micro-cracking, resulting from the high-pressure inter-particle comminution process was believed responsible for generating lixiviant pathways and therefore improving leach extraction recovery.

For certain gold ores HPGRs have been shown to offer significant gold heap leach extraction benefits over alternative dry comminution devices. Examples include the Soledad Project in California (Klingman 2005) and the St Ives Project in Western Australia (Scott 2005).

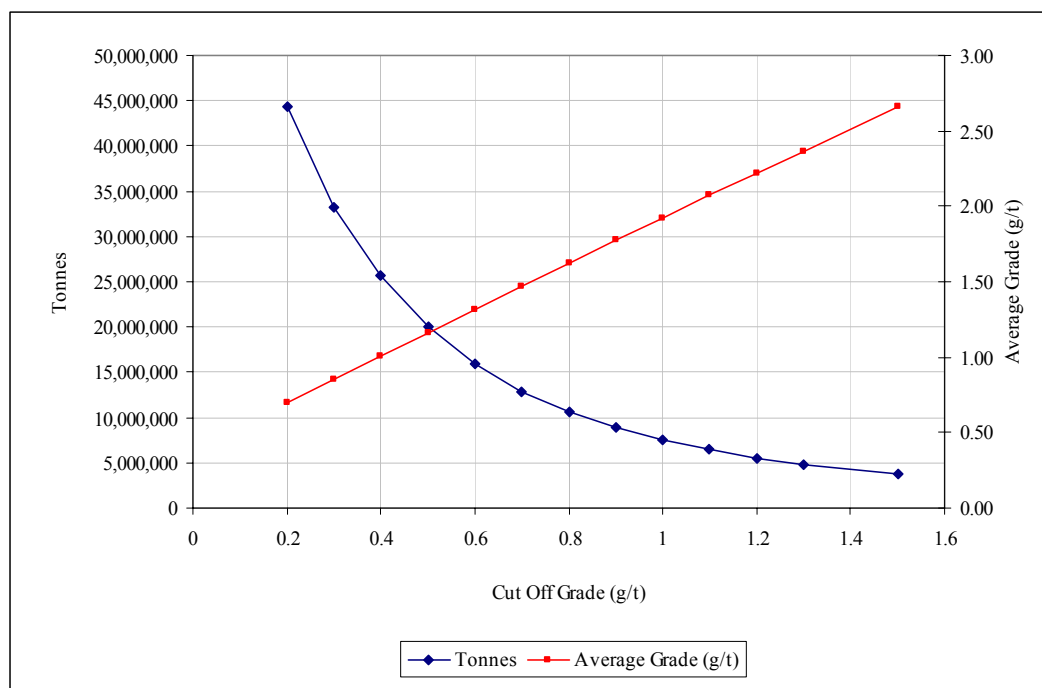
This paper considers the relationship between HPGR comminution effort and gold heap leach extraction for low-grade gold ores. Four recent studies, referred to as A to D, are analysed in varying detail and the lessons from each, both the advantages and the traps and pitfalls, are discussed.

## **2.0 PROCESSING CONCEPT**

Fundamentally, the economic merit of applying HPGR technology to prepare an ore for heap leaching will depend on the leach extraction and the differential compared to alternatives such as standard grinding and CIL/P (or other) processing. The primary question for the latter is to address whether **the additional comminution effort (cost) to grind an ore to a product size typical of a wet grinding circuit is justified by the revenue gained.**

Desk top studies can be undertaken and for projects where both process options are available, a cut-off grade at any throughput for CIL/P versus HPGR Heap Leach can be calculated. Such a study, considering a differential cash flow analysis for CIP versus Heap Leaching, was reported by McLean, 1988. In this paper a 15% absolute recovery differential was assumed. The realised gold price and recovery values assigned are however sensitive to the cut-off grade which in turn influences the mass split of the resource to each process and as a consequence may alter the capital and operating costs. A circular influence results highlighting the importance of understanding the gold recovery for each process. Given this level of sensitivity a sound testwork evaluation process is justified for any proposed Heap Leach and CIL/P hybrid processing operation.

A further positive complication in assessing a combined Heap Leach and CIL/P operation is the influence it has on the mining shell and thus project economics. When profit is added by the processing of low-grade ore, which if mined from within a proposed pit shell is effectively delivered free to surface, the revenue gain can often result in justification for an expanded mining shell. For projects with steep grade versus tonnage curves, as in Figure 2.1, the effect can be significant.



**Figure 2.1 Grade Tonnage Curve Example A**

For the example presented, decreasing the cut-off grade from 0.8 to 0.4 g/t adds approximately 150% or 15 million tonnes to the resource.

Understanding the leach extraction and therefore the lowest cut-off grade that can be fed to a HPGR heap leach circuit is obviously important.

The aim of a project evaluation team is thus to establish the gold grade and recovery window that defines the feed limitations for a HPGR Heap Leach operation. Both the upper and lower boundary and variability of these measures across a resource are crucial to project economics.

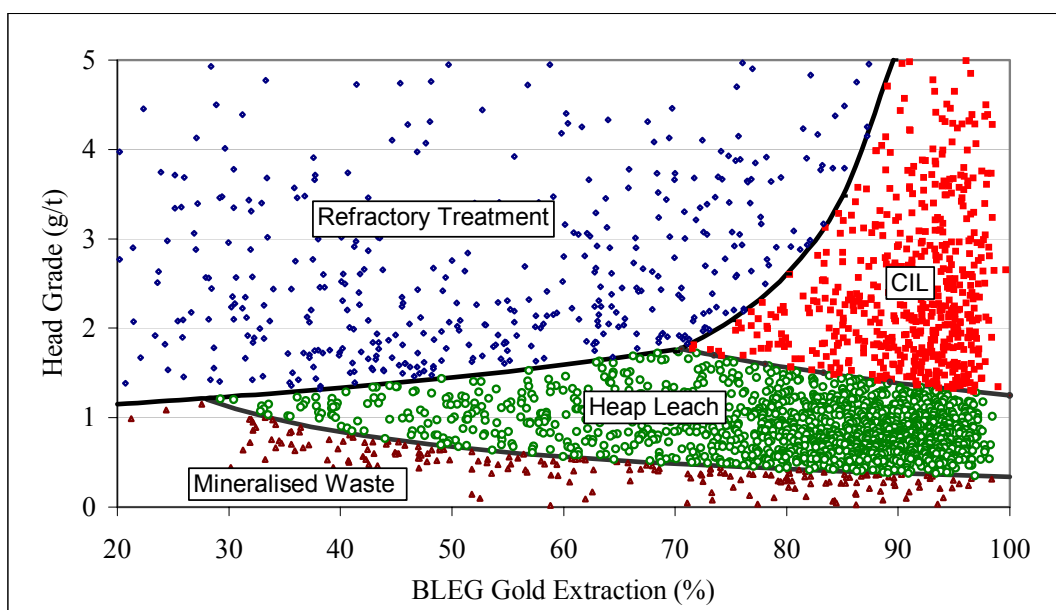
An example of a preliminary analysis on 2832 BLEG<sup>1</sup> results from drill samples within Project A, is provided in Figures 2.2 and 2.3 with operating cost and gold recovery assumptions listed in Table 2-1. For each BLEG result the optimal or most economic process option from an operating perspective is categorised and plotted. The categories considered include “Heap Leach”, “CIL” and “Refractory Treatment” or for those samples that could not generate a positive operating profit, “Mineralised Waste”.

When project economics are considered in totality the financial implications of capital costs, interest rates, logistics, process risk and many other variables will influence the determination of the divisions between the categories presented. Assigning a category by assumed operating profit is therefore viewed as a preliminary evaluation technique with the assumptions in this case provided as an example rather than a guide.

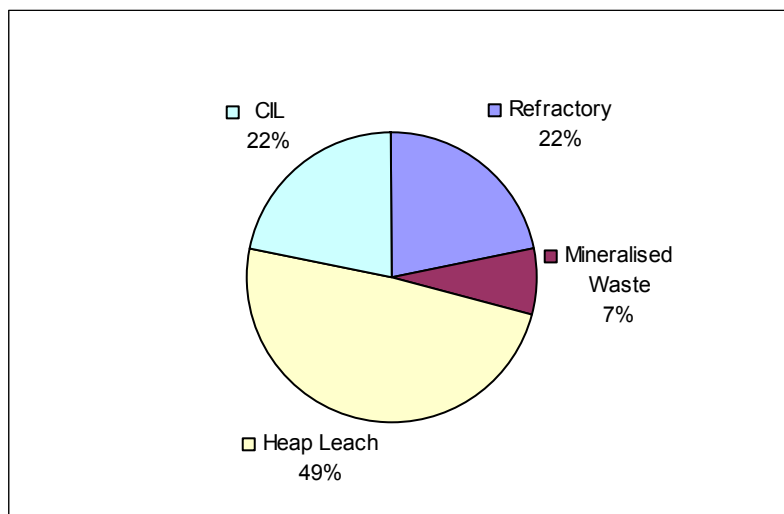
<sup>1</sup> Bulk Leach Extractable Gold

**TABLE 2-1**  
**PROCESS CATEGORY PARAMETERS AND ASSUMPTIONS**

<i>Assumptions</i>		
	Process Operating Cost (\$AUD/t)	Gold Recovery
Heap Leach	5.00	65% of CIL
CIL	15.00	BLEG Result
Refractory Treatment	25.80	BLEG result plus 90 % of leach residue
<i>Gold Price \$AUD 711/oz</i>		



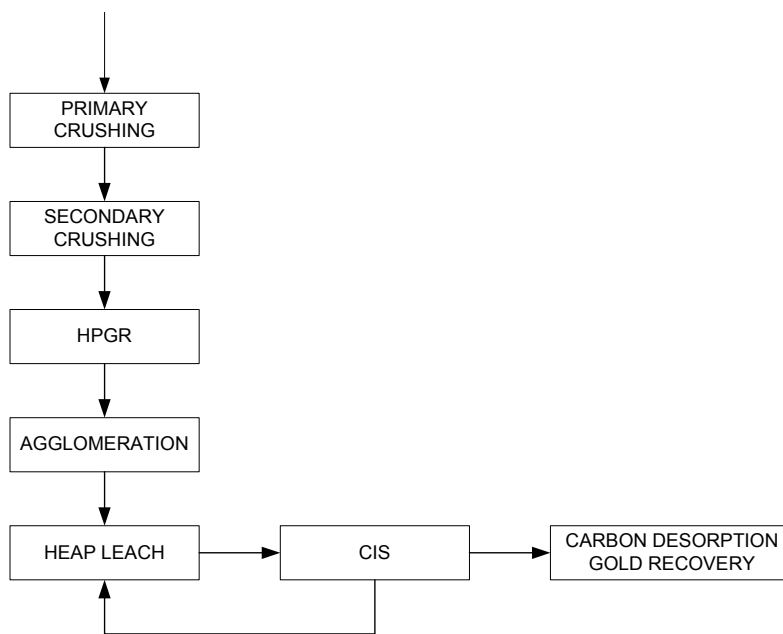
**Figure 2.2** Process Categories Based on Leach Recovery Versus Head Grade



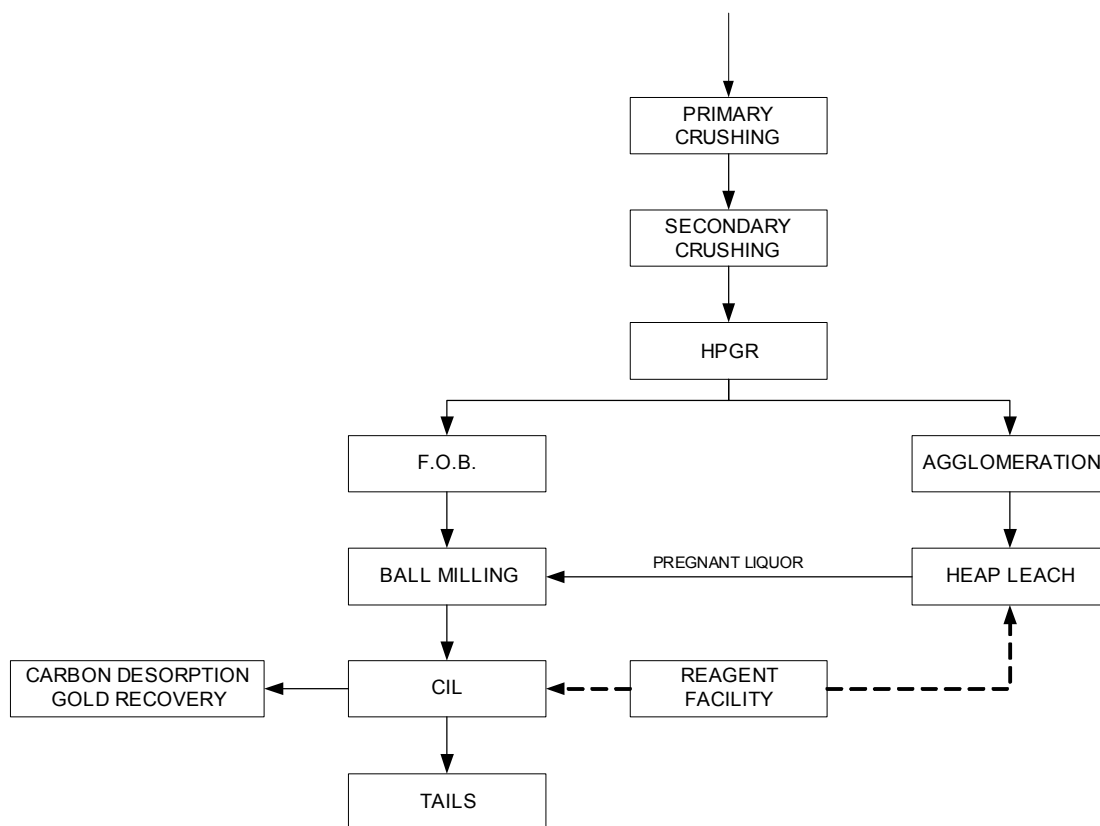
**Figure.2.3 Distribution of BLEG Data by Preferred Process Category**

From the assumptions made in this operating profit analysis there is strong justification to pursue the HPGR heap leach option for this project.

Examples of a proposed stand-alone HPGR prepared Heap Leach flowsheet and a HPGR CIL/P Heap Leach Hybrid circuit are illustrated in Figures 2.4 and 2.5. The hybrid circuit approach, which utilises a HPGR to prepare ball mill feed for the CIL/P circuit and Heap Leach ore on a campaign basis, is advantageous. Economies of scale can be gained by the use of a larger singular crushing circuit, reagent and carbon desorption circuit and the Heap Leach pregnant liquor could be used directly as process water in the CIL/P plant.



**Figure 2.4 HPGR Heap Leach Flowsheet**



**Figure 2.5 HPGR CIL/P and Heap Leach Hybrid Flowsheet**

The application of HPGR prepared Heap Leach processing is advantageous for large tonnage projects with the following characteristics:

- ❖ Fresh rock ores with high Bond Rod and Ball Work Indices.
- ❖ Low-grade free milling ore.
- ❖ High gravity recoverable or coarse gold content ores.
- ❖ Low reagent consuming ores.
- ❖ Projects with relatively high power costs.
- ❖ Projects with steep grade tonnage curves

The effect of HPGR preparation in applications such as sulphide ore and biological heap leaching is not covered in this paper, however it may present opportunity for further investigation.



### 3.0 ORE CHARACTERISATION

Results from four separate Western Australian fresh rock gold projects are discussed in the following sections. To provide background to each case, the relevant ores and comminution properties are summarised in Table 3-1.

**TABLE 3-1**  
**GOLD PROJECTS AND COMMINUTION PARAMETERS**

	Unit	Project A	Project B	Project C	Project D
<b>Geological Setting</b>		Shear-hosted within Archean sediments	Shear-hosted Granite	70% Mafic 30% Porphyry	Sheared high grade metamorphic gneiss
<b>UCS</b>					
Average	MPa	81	153	69	NA
Range	MPa	38 – 171	113 - 188	29 - 116	NA
<b>Abrasion Index- Ai</b>	g	0.43	0.37	0.41	0.60
<b>Crushing Work Index</b>	kWh/t	9.4	NA	17.1	NA
<b>Rod Mill Work Index</b>	kWh/t	19.1	16.6	NA	15.6
<b>Ball Mill Work Index</b>					
P <sub>80</sub>	µm	83	119	79	87
Wi	kWh/t	15.8	14.5	16.7	18.3
<b>SG</b>		2.67	2.73	2.78	2.69
<b>Appearance Functions</b>					
A x b		28.9	28.8	40.0	42.4
ta		0.52	0.24	0.34	0.25

NA – Not available

#### 4.0 HPGR LEACH LIBERATION

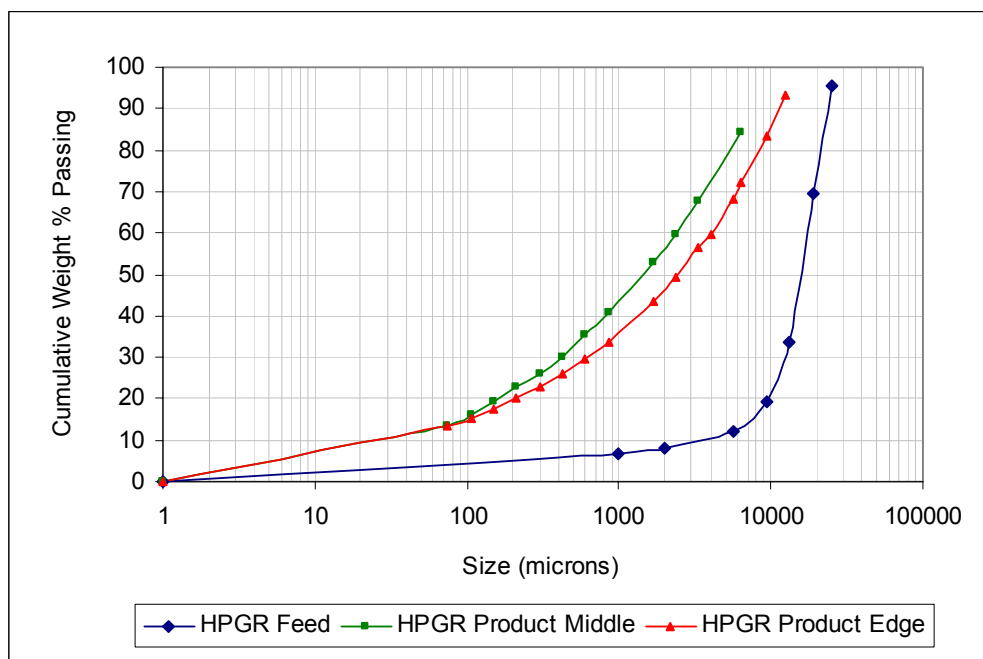
As highlighted in the Processing Concept section, understanding the relationship between comminution effort and leach extraction is paramount to the study of a potential HPGR Heap Leach operation. An example of a preliminary study investigating gold extractions for 5 day cyanide bottle roll leaches on Deposit A ores is presented in Figure 4.1. The P<sub>80</sub> 75 µm test was prepared using a standard laboratory rod mill and all others tests referenced with the P<sub>100</sub> were prepared using a laboratory scale jaw crusher.



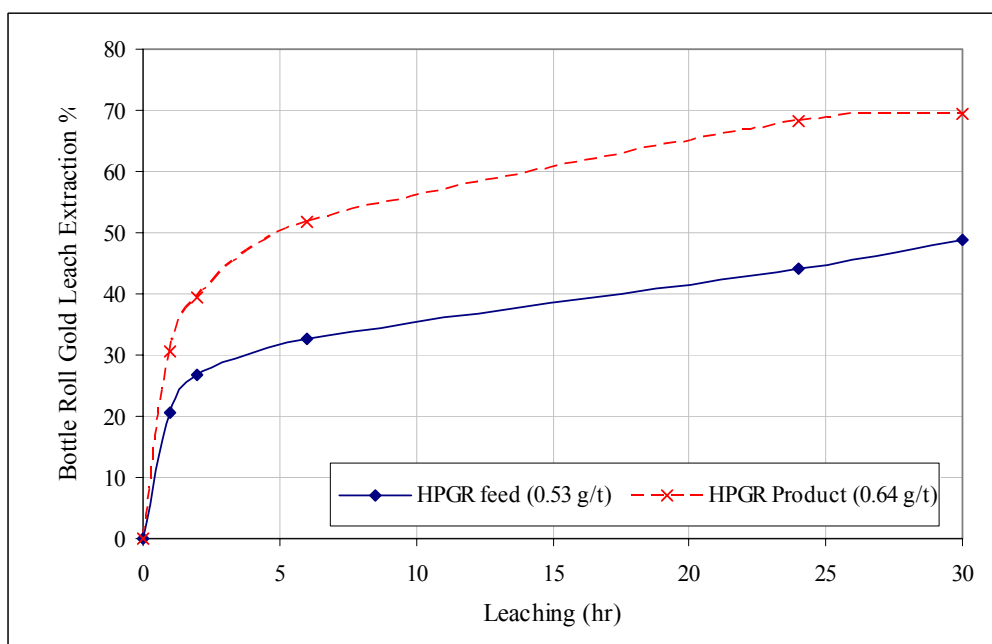
**Figure 4.1 Ore A – Comminution Effort Versus Cyanide Leach Extraction**

A 66% total gold extraction at P<sub>100</sub> 2 mm was considered an encouraging result for this first pass investigation.

As a further example, solution gold extractions from low-grade Project B material indicate that closed circuit secondary crushing is likely to generate recoveries of 0.2 – 0.3 g/t. An additional single pass through a HPGR improves recoveries to 0.3 – 0.5 g/t. Illustrations of the particle size distributions (PSDs) and the 30 hour bottle roll leach kinetics are shown in Figures 4.2 and 4.3.



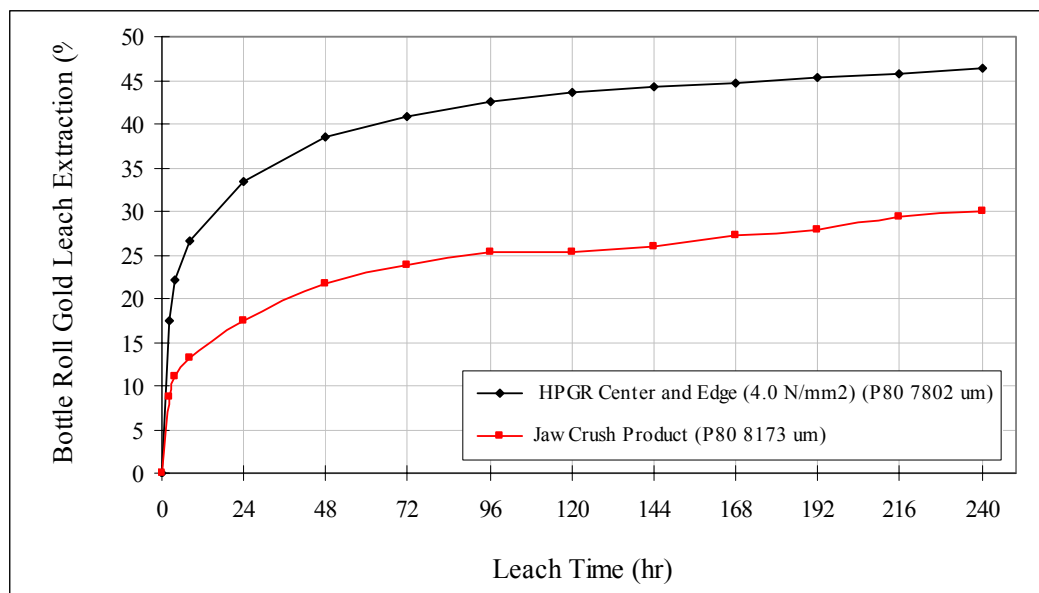
**Figure 4.2 HPGR Feed and Product PSDs**



**Figure 4.3 HPGR Feed and Product Middle Bottle Roll Leach Recoveries**

In a result similar to the previous example, a gold leach extraction of 69% was returned. In this case, a HPGR was employed to prepare a leach feed of P<sub>80</sub> 5.5 mm.

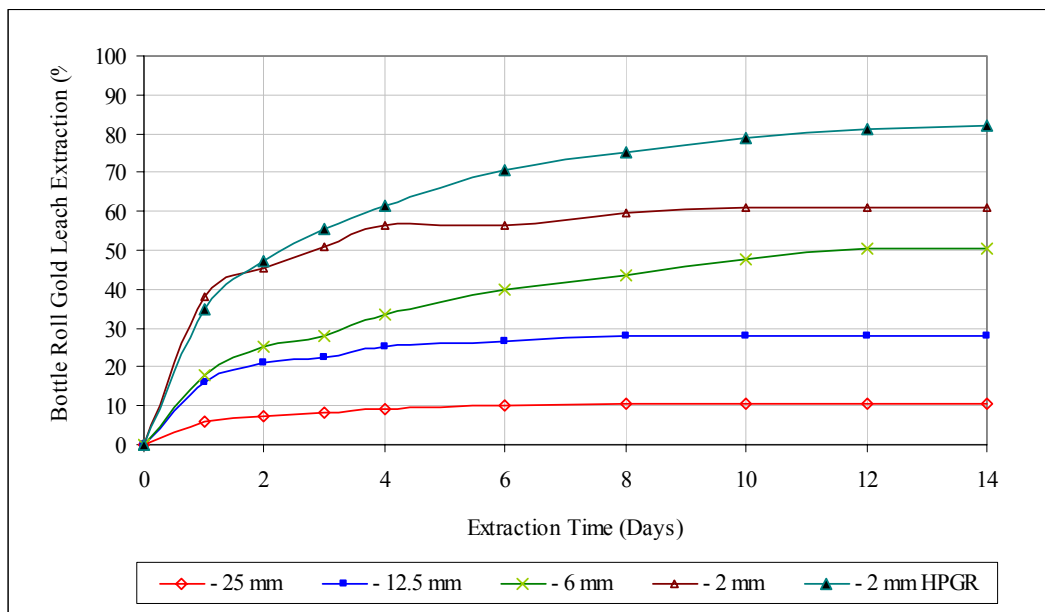
The comminution device has been shown to influence the gold extraction and extraction kinetics of low grade gold ores. An example for Sample A ore, comparing a HPGR product at P<sub>80</sub> 7.8 mm to a jaw crushed product P<sub>80</sub> 8.2 mm is presented in Figure 4.4.



**Figure 4.4 Sample A - HPGR and Jaw Crush Product Leach Profiles**

Significantly greater initial leach rate and total gold extraction was realised for the HPGR product.

A further example of the relationship between gold bottle roll leach extraction and comminution effort for Project D ore is illustrated in Figure 4.5. In this comparison conventional crushed PSDs from -25 mm to -2 mm and a HPGR prepared -2 mm feed are considered.



**Figure 4.5 Sample D - HPGR and Jaw Crush Product Leach Profiles**

A very significant gold extraction increase, from 61 to 82 %, is returned for the HPGR prepared -2 mm feed.

Directly comparing leach extraction performance from machines that inherently produce a differing PSD can however be misleading. Both the increased fines production from the HPGR and the influence of micro-fracturing can contribute to the improved leach extraction. The following section investigates the quantification of these two benefits.

## 5.0 EFFECT OF HPGR PRESS FORCE

For the majority of projects studied by OMC to date, the HPGR pressing force has been found to be a sensitive operational variable with respect to leach extraction and predicted operational cost. When heap leach liberation is targeted rather than size reduction as for a ball mill feed preparation, the most energy efficient HPGR operation may not be optimal. The option of closed circuit operation at low press force should therefore be compared to open circuit operation at higher press force with or without edge recycle.

A detailed investigation of the effects of HPGR pressing force was undertaken recently on a master composite sample from Project C. Leach responses for seven HPGR press tests ranging from 2 to 8 N/mm<sup>2</sup> press force were compared against four cone crush products ranging from 2 to 6.3 mm P<sub>100</sub>. Figures 5.1 and 5.2 illustrate the PSDs and include total gold leach extraction for each test considered.

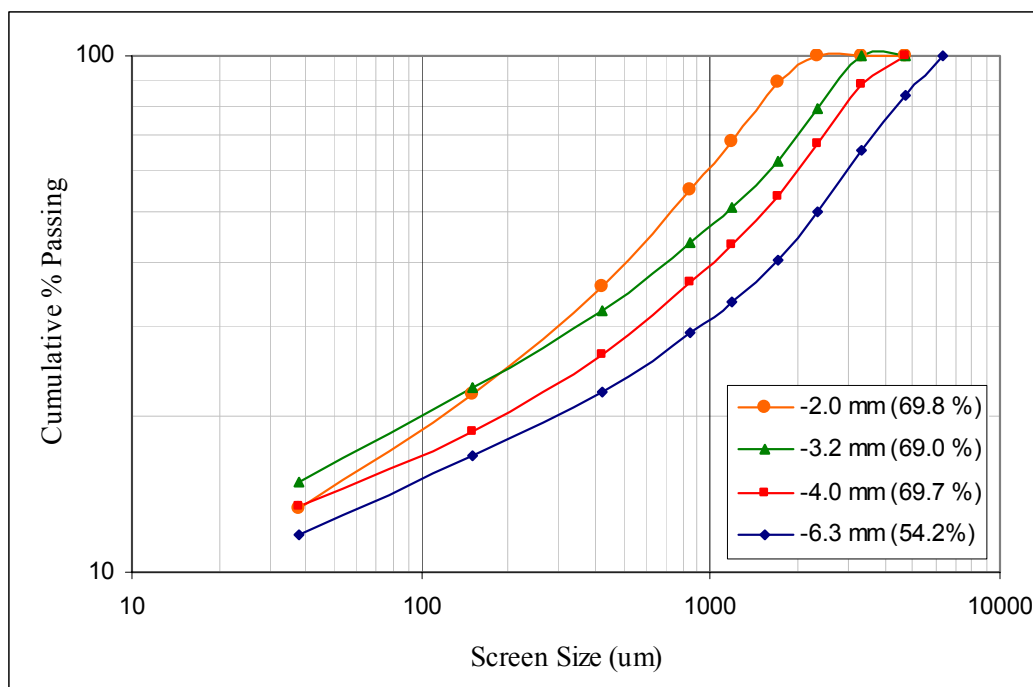
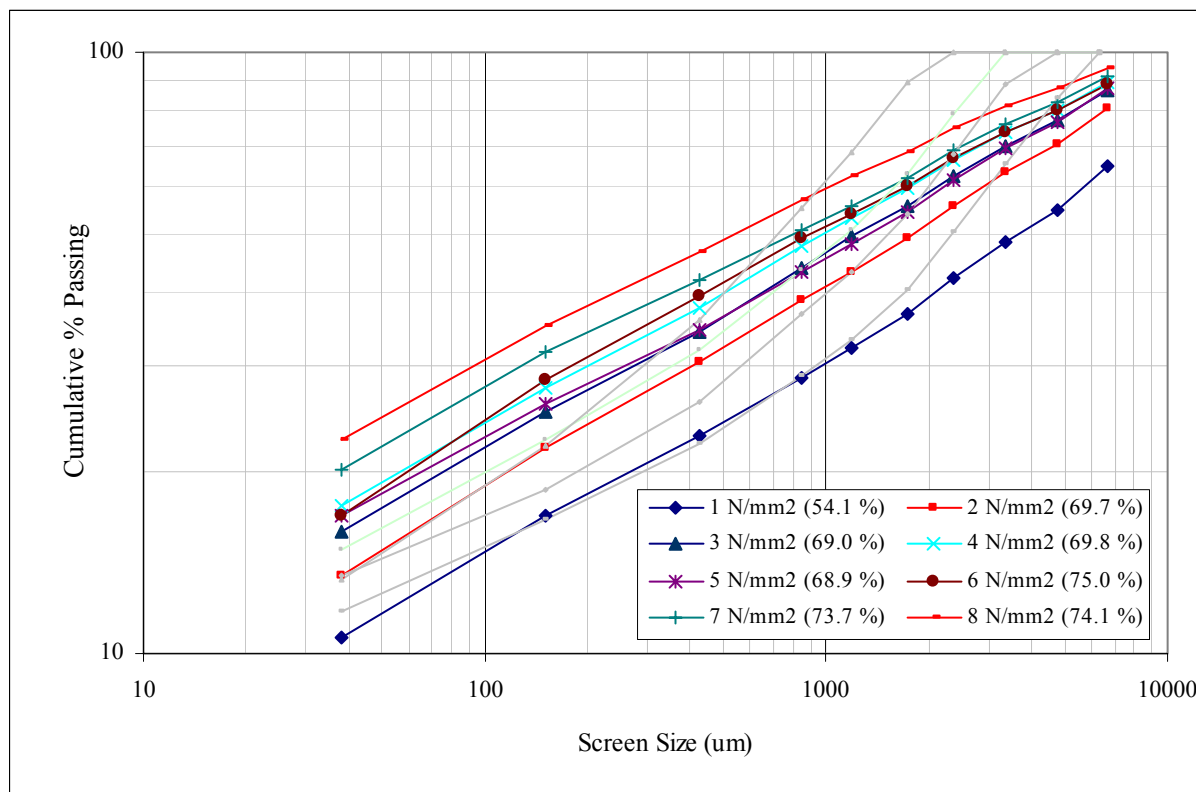


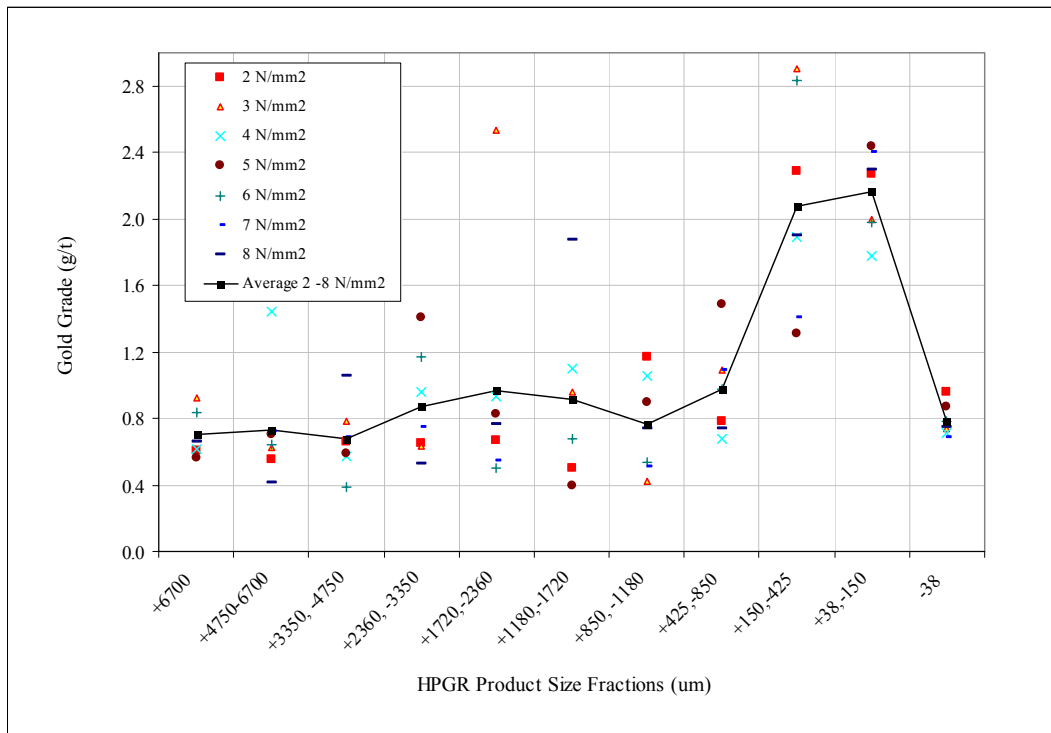
Figure 5.1 Sample C –Cone Crush PSDs and Calculated Gold Leach Extractions



**Figure 5.2 Sample C –HPGR PSDs by Press Force and Calculated Gold Leach Extractions**

The characteristic fines rich HPGR distributions are clearly evident compared to the cone crush product distributions. Slightly higher leach extractions are also associated with the HPGR results, ranging from 54 to 75 % compared to the cone crushed ore at 54 to 70%.

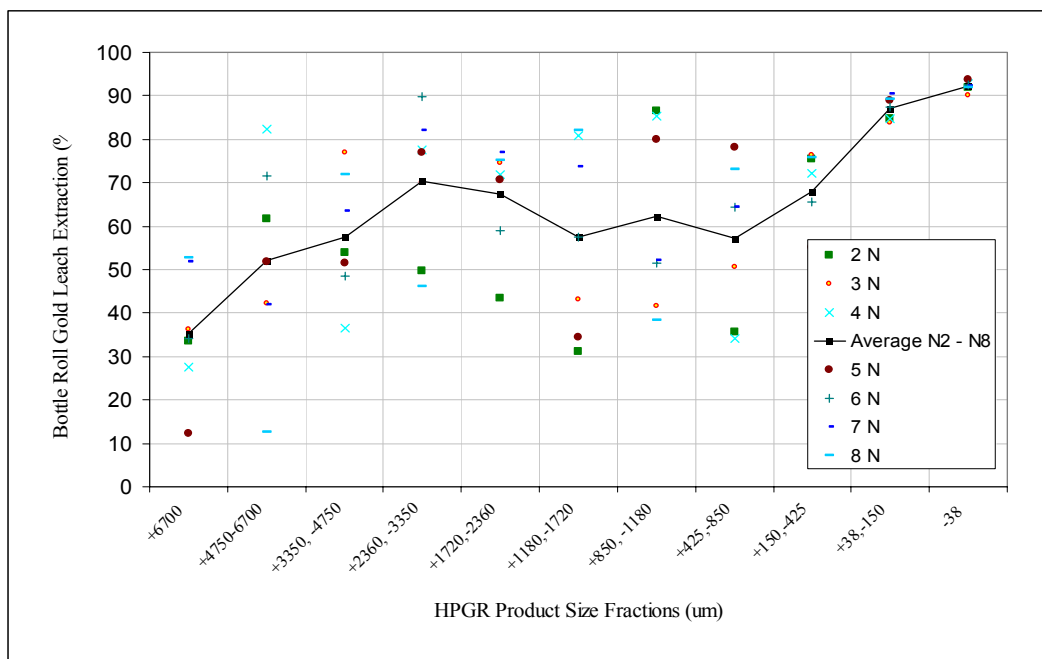
Figure 5.3 illustrates the natural gold deportment for size fractions from each of the seven HPGR pressure tests. Generally the gold grades by size fraction are similar across all pressure tests, with a consistent (approximate 2.5 times) elevation in the 38 to 425  $\mu\text{m}$  range. Such an outcome is not unusual and indicates some preferential gold liberation has occurred.



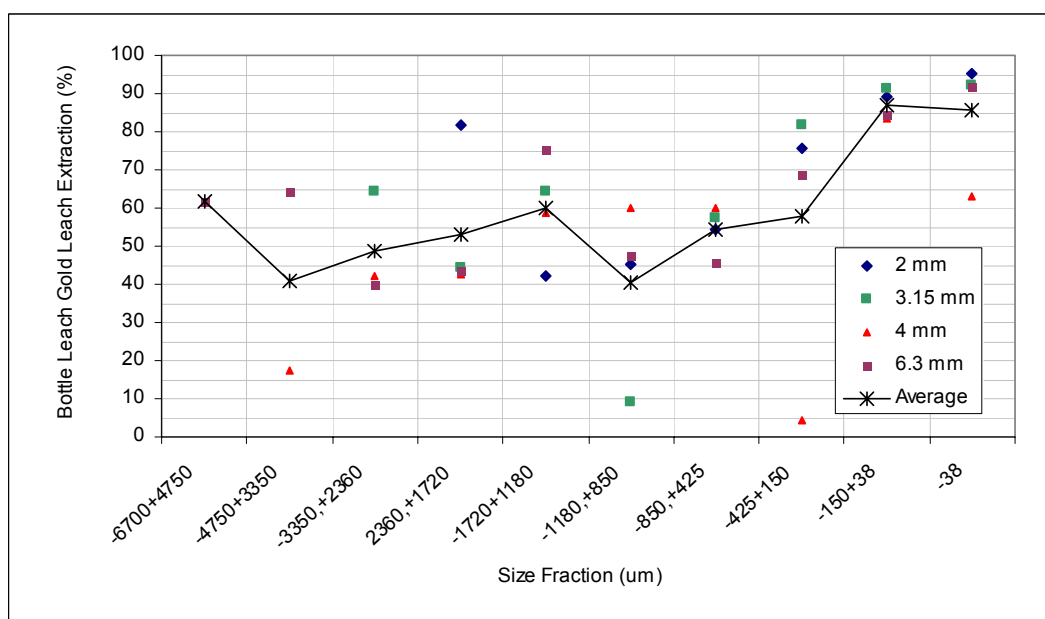
**Figure 5.3 Sample C – Effect of HPGR Press Force on Product Size Fraction Gold Grade**

Each size fraction from both the HPGR and cone crusher products underwent an individual bottle roll leaching test with the results and an average trend line presented in Figures 5.4 and 5.5.





**Figure 5.4 Sample C – Effect of HPGR Press Force on Product Size Fraction Leach Extraction<sup>2</sup>**

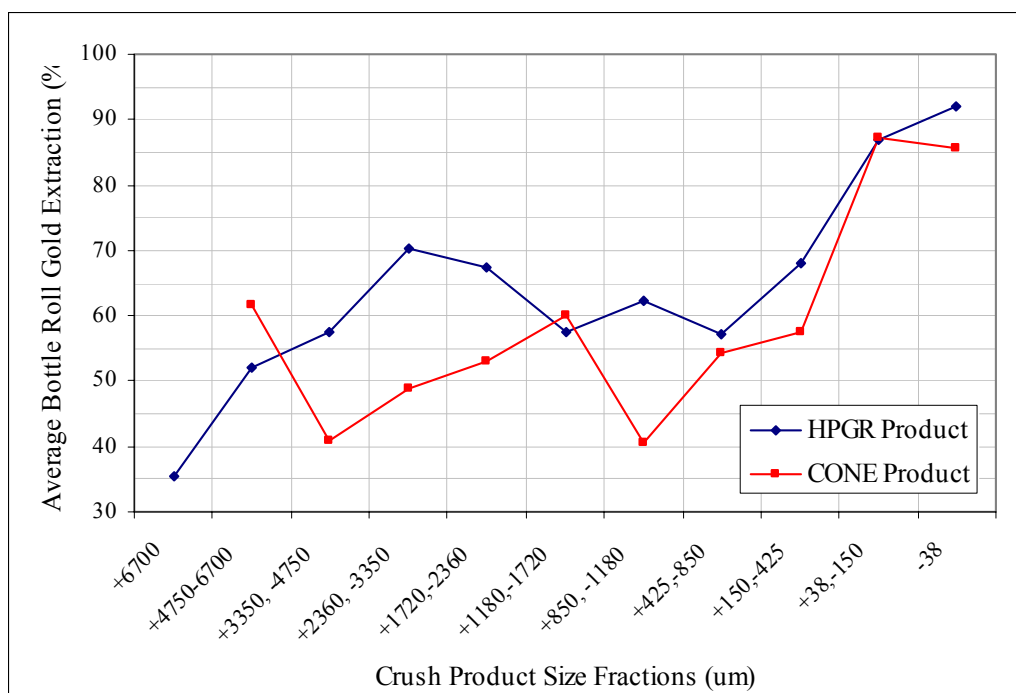


**Figure 5.5 Sample C – Effect of Cone Crush PSD on Product Size Fraction Leach Extraction**

<sup>2</sup> HPGR tests used the 750 x 250 mm Koeppern hexadur<sup>®</sup> roll at AMMTEC Perth, Western Australia. Bottle rolls were completed over fourteen days with 4 kg of each size fraction from a middle and 10% edge recycle product composite.

No distinct trend in gold extraction within each size fraction was evidenced for either the HPGR or cone crushed products. Some notable outliers and a relatively elevated variance in extractions were however observed. Further repeat testing would be necessary to statistically quantify these effects although the costs were prohibitive at the time.

The average leach extraction across size fractions for each machine is compared in Figure 5.6.



**Figure 5.6 Sample C – Comparison of Average Gold Leach Extraction by Size Fraction**

Similar high leach extractions are observed for both the cone crush and HPGR products at less than 150  $\mu\text{m}$ . For this size range it is comparable to that historically recorded when milling the ore to  $P_{80}$  75  $\mu\text{m}$ . Coarser size fractions generally indicate a higher value for the HPGR prepared material, which is consistent with findings by Patzelt when leaching a siliceous gold ore from Nevada, (Patzelt et al, 1995). A particularly anomalous peak is observed for the average HPGR product between 1.7 and 3.3 mm. This effect is likely to be indicative of the micro-fracturing advantage achieved after high pressure comminution in an HPGR.

Through establishment of an understanding of the leach extraction trends by size fraction, normalisation for the PSD differences between a cone and HPGR product can be achieved and a direct assessment of the effects of micro-fracturing formulated. Such an analysis is achieved by coupling the average size by size leach extraction data for each machine with the product PSDs, Table 5-1.

It is however acknowledged that the approach taken is simplistic and assumes the extraction by size is consistent across all cone crush or HPGR PSDs. Logic would suggest that the advantage from micro-fracturing would increase with the applied press force.

**TABLE 5-1  
 PREDICTIONS OF LEACH EXTRACTION INCREASE DUE TO  
 HPGR MICRO-FRACTURING**

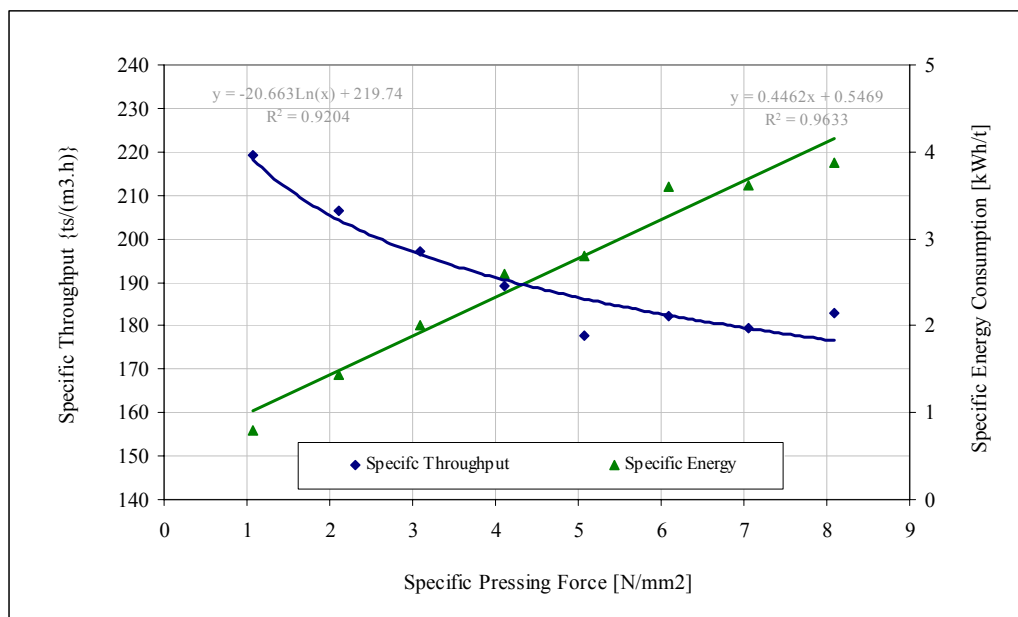
PSDs		Predictions using average size by size extraction		Leach Extraction Increase (%) (Micro-fractures)
		HPGR	Cone Crush	
<b>Cone Crush</b>	-2 mm	74.6	69.6	7.1
	-3.14 mm	84.3	75.6	8.7
	-4 mm	54.7	48.1	13.7
	-6.3 mm	61.3	55.4	10.7
			Average	<b>10.7</b>
<b>HPGR</b>	1 N/mm <sup>2</sup>	66.9	58.0	15.5
	2 N/mm <sup>2</sup>	72.8	65.9	10.5
	3 N/mm <sup>2</sup>	70.7	63.4	11.5
	4 N/mm <sup>2</sup>	70.3	64.4	9.1
	5 N/mm <sup>2</sup>	72.6	65.7	10.5
	6 N/mm <sup>2</sup>	72.9	66.2	10.1
	7 N/mm <sup>2</sup>	73.8	68.5	7.6
	8 N/mm <sup>2</sup>	73.7	67.9	8.6
			Average	<b>10.4</b>

The overall micro-fracturing related leach extraction advantage of HPGR over cone crushing was predicted at 10 to 11%. In the context of a heap leach recovery process this differential is considered significant.

A similar analysis comparing VSI crushing to HPGR processing a fresh rock quartz latite ore from the Soledad Mountain Project in California was reported (Klingman, 2005). In this comparison 120 to 144 hour bottle roll results indicated an average 16% gold and 19% silver recovery increase for the HPGR product. The VSI products of 100% minus 8 mesh (2.36 mm) were reported to have a finer PSD than the HPGR products generated at press forces ranging 3.2 and 4.1 N/mm<sup>2</sup>. This would suggest that the gold recovery advantage due to micro-fracturing may well be greater if the PSD influence were eliminated.

The HPGR pressing force may have many other process implications other than leach extraction. Some of the significant variables include the heap percolation rate, specific energy, specific throughput, wear rates, machine availability, cake de-agglomeration requirement and reagent consumption.

The specific energy and specific throughput for Sample C are presented in Figure 5.7.



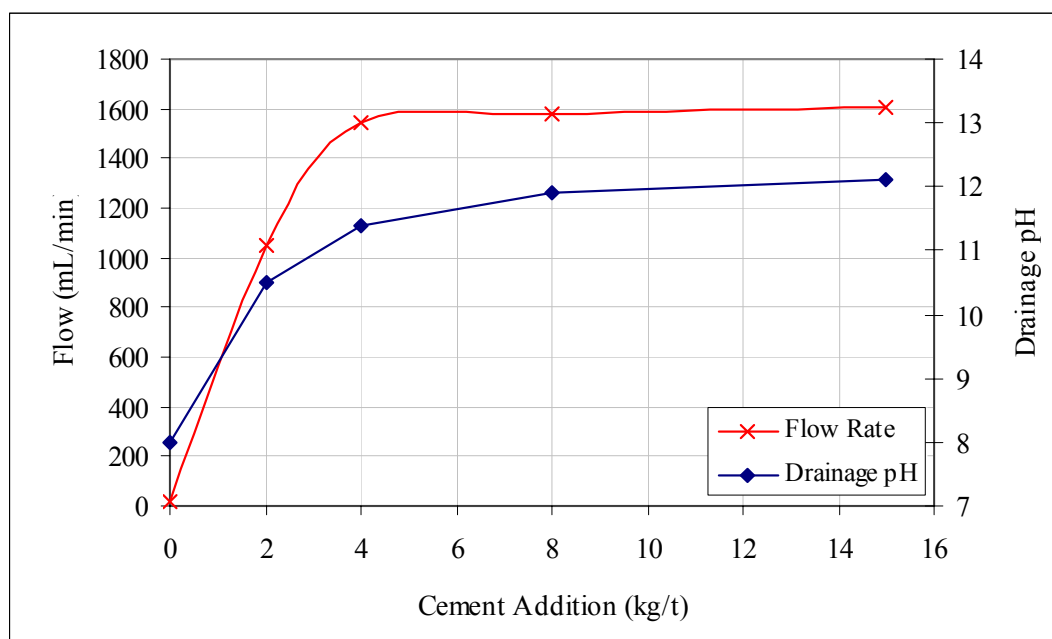
**Figure 5.7 Sample C – Effect of Press Force on Specific Energy and Specific Throughput**

A typical linear relationship between specific energy and press force was returned. The specific throughput is however increasingly sensitive to press force below 5 N/mm<sup>2</sup>.

Other HPGR circuit variables such as the rolls surface, aspect ratio, roll speed, feed moisture, feed PSD, edge recycle and degree of closed circuiting justify consideration in any detailed process analysis. Furthermore, scaling up from a pilot size HPGR unit to a full scale unit will have some effect in coarsening the product PSD. As such the leach extraction implications need to be well understood.

## 6.0 EFFECT ON HEAP LEACH PERCOLATION RATE

One of the key detrimental features of decreasing the feed size to a heap leach, whether by the application of increasing HPGR rolls pressure or closed circuiting, is the negative effect on heap percolation rates. This is particularly notable for a HPGR product which has a fines ratio well suited to blocking flow through the heap matrix. Results from laboratory scale 80 mm diameter column flow tests on Sample A are illustrated in Figure 6.1.



**Figure 6.1 Sample A - HPGR Product Percolation Flow Rates (4.4 N/mm<sup>2</sup> press force, P<sub>80</sub> 7.8 mm)**

The pressed biscuit readily broke down to produce dust and fines that hindered percolation. Cement addition was therefore mandatory and application rates of 4 to 6 kg/t were found necessary to provide long term structural integrity to the agglomerates. No flow testing under load was undertaken to simulate full scale conditions. Note that the cement provides protective alkalinity for cyanide leaching and replaces the lime addition that would otherwise be made.

As an alternative to agglomeration, wet separation of the fines could be considered particularly if they exhibit more elevated gold values and can be pumped directly to the adjacent CIP/L circuit.

## 7.0 SCALING UP FROM BOTTLE ROLL TO COLUMN TESTS

Limited data is available on scale up from bottle rolls to column testing of HPGR prepared cement agglomerated gold ores. A comparison was completed for Ore A with a summary of results included in Table 7-1.

**TABLE 7-1**  
**SCALE UP FROM BOTTLE ROLL TO COLUMN TESTS (ORE A)**

		<b>4 kg Bottle Roll (10 day leach)</b>	<b>50 kg Column Test (48 – 62 day leach)</b>	<b>Variance (% of bottle roll result)</b>
<b>Sample 2</b>	Reconstituted Head Grade	0.79	0.74	-6.3
	Leach Extraction	35.4	47.6	34.5
<b>Sample 3</b>	Reconstituted Head Grade	0.37	0.25	-32.4
	Leach Extraction	32.2	73.2	127.3
<b>Sample 4</b>	Reconstituted Head Grade	0.77	0.94	22.1
	Leach Extraction	57.5	75.6	31.5

Results indicated the gold leach extraction to be consistently higher for the column tests, and the reconstituted head grade variable. The relatively high variability suggests the 4 kg bottle rolls should be viewed as indicative, and more reliability placed on the results from the column leaches of 12.5 times greater mass.

## 8.0 ANALYTICAL ISSUES

The low grade of ore and generally heterogeneous or “spotty” distribution of gold particles often presents difficulties in sample and assay repeatability.

To improve the representivity of results the following methods were found to be practical:

- Calculation of the head grade and recovery using only a reconstitution of the leach solution gold and residue gold.
- Rigorous blending, splitting and pulverisation practices.
- Using a screen fire method for analysis of solids. This entails standard grinding of the sample with a ring mill and wet screening of the product at 75  $\mu\text{m}$  aperture. The low mass + 75  $\mu\text{m}$  material, potentially containing the coarse gold, is assayed by fire assay and the -75  $\mu\text{m}$  fraction sub sampled and assayed in triplicate by a wet chemical method or by fire assay.
- Duplicate or triplicate bottle rolls of at least 4 kg.
- Column leach tests of at least 50 kg.
- The accuracy of testwork sampling and analysis is as critical as that used in the resource estimation and mine planning processes. For many WA gold ores the heterogeneous nature of the gold distribution in situ makes ore modelling and differentiating between 0.6 and 0.8 g/t cut-off boundaries challenging. There is however risk advantages if a low grade low cost processing option is available as this offers some operational insurance against a significantly sub economic ore parcel being included within the milling schedule.

## 9.0 PROCESS DEVELOPMENT STAGES

To date there is little documented operational precedent for a HPGR prepared Heap Leach operation. Furthermore there is a limited database for HPGR operation in hard rock applications and the capital costs for these units are significant. A slow cautious approach to testing and design, as outlined in Stages 1 to 5 following, is therefore justified. A typical Stage 1 to 3 prefeasibility assessment program for a medium sized operation (3-6 Mtpa) is estimated to take between 9 and 18 months.

### *Stage 1*

Mining pit models incorporating a preliminary investigation of the low grade ore processing economics to support progression to Stage 2. Preliminary mass weightings and scheduling of low and high grade ore to define initial design criteria and therefore enable a basis for preliminary circuit sizing and derivation of indicative capital and operating costs.

### *Stage 2*

HPGR testwork to define the specific throughput, specific energy and wear rate predictions for the likely range of operating pressures.

Preliminary ~ 4 kg cyanide leach bottle rolls on samples from the major ore domains exploring the relationship between crush / grind PSD and recovery. Preliminary reagent consumptions and leach rates are determined.

Preliminary percolation rate tests to establish the relationship between product PSD and agglomeration requirements.

Revision of the economic mine model to justify progressing to Stage 3.

### *Stage 3*

50 kg or larger column leach tests on HPGR products to evaluate the optimised or advantageous parameters found in Stage 2 and generate preliminary engineering design criteria.

Key considerations for a HPGR feed preparation circuit include:

- A wet or dry closed circuit at lower press force or open circuit with or with out edge recycle.
- Roll surface type.
- Fines removal or agglomeration requirements down stream.
- Aspect ratio of HPGR which influences product PSD, % edge material, wear rate and feed top size.



The relationships between HPGR operating press force, aspect ratio, tyre surface, wear rate, power consumption, agglomeration capital and operating cost and gold leach extraction is complex. With well-designed representative testwork data the optimised operation could be determined using a multivariate analysis method.

***Stage 4***

Pilot scale operation – 10 000 – 50 000 tonne heap leach pads to develop final design criteria and define the project economics.

***Stage 5***

Detailed Engineering Design.

Project Implementation.

## 10.0 CONCLUSIONS

The concept of HPGR feed preparation for a fresh rock low grade gold heap leach has merit for large tonnage projects particularly with the following characteristics:

- ❖ Fresh rock with high Bond Rod and Ball Work Index
- ❖ Low-grade free milling ore
- ❖ High coarse gold content ores
- ❖ Low reagent consuming ores
- ❖ Projects with relatively high power costs
- ❖ Projects with steep grade tonnage curves
- ❖ CIL/P treatment of the higher grade portion of the resource.

HPGR technology can offer advantages over conventional crushing equipment for heap leach treatment of some low grade fresh rock gold ores. Rudimentary analysis has indicated that for Type C low grade gold ore an additional 10-11% leach extraction is realised by the HPGR over conventional cone crushing following normalisation for the PSD effect. This difference can be explained by the penetration of leach solution into the micro-fractures created by high pressure comminution within the HPGR.

The relationship between HPGR operating press force, wear rate, specific power consumption, specific throughput, agglomeration capital and operating cost and gold leach extraction is complex. Additional economic complexity is introduced through economies of scale relationships for each circuit within a hybrid HPGR heap leach and CIL/P operation. With cooperation between Mining, Geological and Metallurgical personnel, and a well designed testwork program, the optimised operating conditions for a HPGR Heap leach circuit can be determined; however the level of complexity may require a multivariate analysis approach.

The accuracy of testwork sampling and analysis for process design is as critical as that used in the resource estimation and mine planning processes for a fresh rock low grade HPGR prepared heap leach project. A concerted effort should therefore be directed towards optimising all sampling and analysis technique and understanding inherent variability at a statistical level if feasible.

There is no significant documented operational precedent for a HPGR prepared Heap Leach operation. Furthermore there is little precedent for HPGR operation in hard rock applications. A slow cautious approach to testing and flowsheet design is therefore justified. A typical prefeasibility assessment program for a medium sized operation (3-6 Mtpa) is estimated to take between 9 and 18 months.

## ACKNOWLEDGEMENTS

OMC acknowledges the permission and support of clients in the inclusion of data and examples within this paper.

## REFERENCES

Edward J McClean, August 1988, *When is Heap Leaching the Best Choice?* In Proc. Symp. “Economics and Practice of Heap Leaching in Gold Mining”, The Australian Institute of Mining and Metallurgy, Victoria, Australia.

Esna-Ashari & Kellerwessel, H (1988), *Roller Press Comminution Improves Heap Leach Recovery*. Randol Perth International Gold Conference, Perth 28 October – 1 November 1988. pp 50 – 53.

Patzelt, Norbert, Knecht, Hans and Baum W (1995), *Advances in POLYCOM High- Pressure Roll Grinding of Refractory Gold Ores*. Randol Gold Forum, Perth 1995. pp 107 – 123.

Baum W, Patzelt N, and Knecht, Johann (1997), *Metallurgical Benefits of High Pressure Roll Grinding for Gold and Copper Recovery*. SME, Denver, February, 1977. Conference print pp 111 – 116.

Scott T (2005), *HPGR for Heap Leach at St Ives*, Randol Innovative Metallurgy Forum, Perth, August 21 – 24, 2005

Klingerman, H Lutz, (2005), *HPGR Benefits at Golden Queen Soledad Mountain Gold Heap Leaching Project*. Randol Innovative Metallurgy Forum, Perth, August 21 – 24, 2005.

Dunne R, Goulsbra A, Dunlop I.,(1996), *High Pressure Grinding Rolls and the Effect on Liberation. Comparative Test Results*, Randol Gold Forum, Olympic Valley, CA.

Herkonhoff, E.C., and Dean, J.G., (1987), *Heap Leaching: Agglomerate or Deslime?*, Engineering Mining Journal, June 1987, pp. 32-39

Daniel M.J. and Morrell S., (2004), *HPGR Model Verification and Scale Up*, Minerals Engng,17, pp 1149 – 1161.