The Pre-Concentration Of Precious And Base Metal Deposits Using The Inline Pressure Jig (IPJ); Higher Feed Grades And More Metal.

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ABSTRACT

Pre-concentration of precious metal and base metal ore types is becoming more relevant with the discovery, development and operation of many lower grade deposits around the world. The fluctuations in metal prices expose many mines to risks especially dealing with low and variable ore grades.

Pre-concentration, the process of concentrating the valuable metal into a smaller mass yield, effectively results in the introduction of higher feed grades to milling circuits. Gangue Rejection, the removal of lower S.G. waste rock from the circuit; not only results in higher downstream grades but also potentially removes harder, non-valuable mineral, providing significant power savings within the circuit. The pre-concentration or 'gangue rejection' process offers a number of benefits when considering the treatment of marginal ore deposits, especially if it can be performed at a coarse crush size; these benefits include a reduction of the operating costs and the feed of more metal units to the mill.

Gekko Systems has effectively utilized the Inline Pressure Jig (IPJ) to pre-concentrate the valuable metal, achieving high primary recoveries into a range of mass yields resulting in upgrade ratios between 2 and 10 times.

This paper explores: the benefits of pre-concentrating 'marginal' ore deposits prior to the milling circuit; the selective rejection of ore types that may affect either the recovery or comminution process; and also looks into the potential to effectively reduce the 'cut-off' grade when considering the mine planning process. Case studies of projects using the IPJ to pre-concentrate and reject gangue are also included.

Pre-concentration and gangue rejection provide the potential to develop marginal ore deposits, thus providing higher grades, less gangue and more metal at a lower operating cost to producers.

Keywords: pre-concentration, gangue rejection, liberation,

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Introduction

The grades of the world's base metal and gold deposits are dropping. The average gold grades for the past 18 years have been 1.18 g/t from producing mines, with current undeveloped reserves averaging 0.89 g/t (Desjardins, 2014). This is a growing trend not only in gold deposits but also in base metal deposits. From 2001 to 2012, the weighted-average head grade at 47 producing mines declined by almost 30% (Desjardins, 2014).

The cost of treating gold ores has also escalated dramatically; it has been reported that gold companies' 50th percentile operating costs are US$1200/oz, with this trend also evident in base metals. Cash operating costs at major copper mines have tripled over the past 10 years up to an average of US$1.50/lb in 2012 (Blamey, 2013).

Capital costs to develop lower grade deposits are also on the increase. The capital intensity for a new copper mine in 2000 was between US$4,000 – US$5,000 to build the capacity to produce a tonne of copper, on an annualized basis; now the average capital intensity is above $10,000/t (Mills, 2014).

With the combination of decreasing grades, higher operating costs and increasing capital costs, companies are struggling to make economic margins. Metal price variability and the cyclical nature of the industry, along with hedging, currency fluctuations, technical risk and shareholder demands for dividends, all combine to increase the project risk, especially for lower grade deposits.

New technology is one option available to miners; however current technologies are not changing rapidly and many improvements in the mining equipment available are due more to smart and innovative incremental improvements to existing technology. This, along with the industry's 'snail like' acceptance of new technology, makes it difficult for many metallurgists to escape from the old paradigms and think 'outside the box'.

Metallurgists and process engineers are being encouraged to employ tools that are readily available and, at the same time, also come up with new processing flowsheets to combat the issues associated with low grade deposits. There is a need to focus on the net present value, i.e. profitability and not recovery for recovery's sake.

Pre-concentration and gangue rejection of waste is one option available to the industry that can provide many benefits in processing low grades.

Pre-Concentration and Gangue Rejection

Pre-concentration can be considered as a discrete process step ahead of the main recovery process, aimed at rejecting coarse waste by exploiting the physical properties of the ore (Shirley, 2009). Put simply, it is a process that enriches the ore.

This is not a new concept in mineral processing. There is a range of options for pre-concentration, including flotation, screening, optical sorting, x-ray sorting, dense media separation and gravity separation. Each offers its own advantages in terms of throughput, feed size range, capital cost and operating cost.

Another similar concept to upgrade or enrich the ore is 'gangue rejection'. Although it is also a process of enriching the ore for downstream treatment, it is effectively removing the gangue or deleterious elements that may affect the downstream process. A common example would be the rejection of hard scats from a milling circuit. A pebble crusher is unlikely to be used if the grade of the 'scats' is below the 'new feed' head grade, making it uneconomic to reprocess (Powell et al, 2010). Gangue rejection is also employed within a process plant to remove deleterious material with a low specific gravity (S.G), or fine graphitic and saprolitic clays that also cause issues in the downstream CIL or flotation circuits.

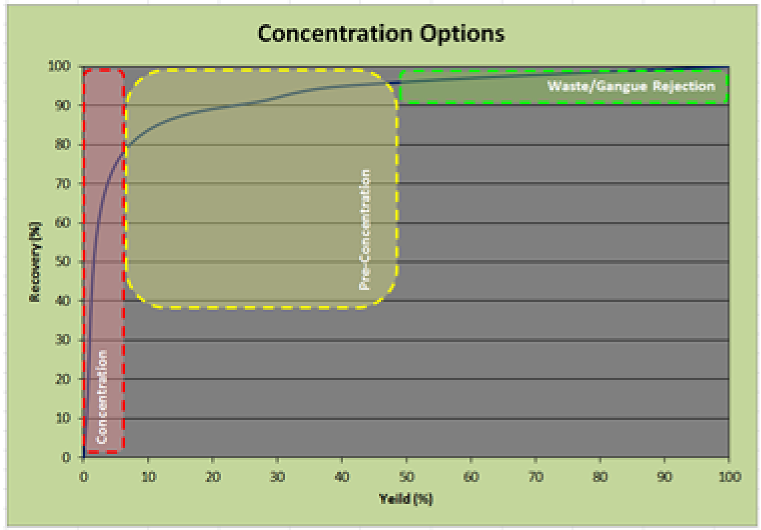

Figure 1 - Definition of Concentration Options

Gekko Systems, a company specialising in pre-concentration considers 'Concentration' being the recovery of the valuable metal into the lowest possible mass yield, making the highest possible grade. This occurs within the steepest part of the yield–recovery curve (Figure 1). Some examples include; cleaner flotation, batch centrifugal concentrators, spirals and tables. 'Pre-concentration' is defined as recovering as much of the valuable metal into the optimum mass yield and is often considered as a roughing process. This is normally associated with continuous concentrators, such as rougher flotation and jig circuits where maximum recovery is the key focus. However equally important to consider is 'Gangue rejection' by rejecting as much of the low S.G, deleterious or waste material as possible without compromising recovery. This occurs as the yield-recovery curve 'flattens' out. This often requires both continuous rougher and scavenger equipment in order to be able to recover enough mass to concentrate. This is often overlooked in many metallurgical testwork programs and so is now being considered as a discrete test.

Pre-Concentration and Liberation

The potential to increase feed grades or decrease tonnages to high cost downstream processes has major implications for increasing productivity and decreasing energy costs on a per unit metal basis. It is however always a trade-off between the recovery (or the loss of metal units in the pre-concentration process) versus the operating and capital cost of the process. For gold ores pre-concentration makes more sense when looking at sub-economic ore, waste or mullock heaps. A small loss in recovery is not considered a major issue, if the waste can be upgraded to economic mill feed grades and add extra metal units to production.

Stand-alone modular pre-concentration plants can allow mines to produce extra ounces and augment feed to larger milling circuits starved of high-grade feed. The potential to build a pre-concentration circuit larger than a brownfield milling circuit of a certain capacity opens a number of options to clients. It is important to select the correct tool for any pre-concentration application. Of all the methods available, gravity separation is commonly deployed (Smit et al, 2012).

Pre-concentration can be employed within many flowsheets. The biggest advantage occurs when the process can be performed at a coarse liberation size. The energy required to break the ore and liberate the mineral exponentially increases as it gets finer, so the liberation size of the valuable mineral will dictate the operating cost and the method of pre-concentration that can be employed (Figure 2).

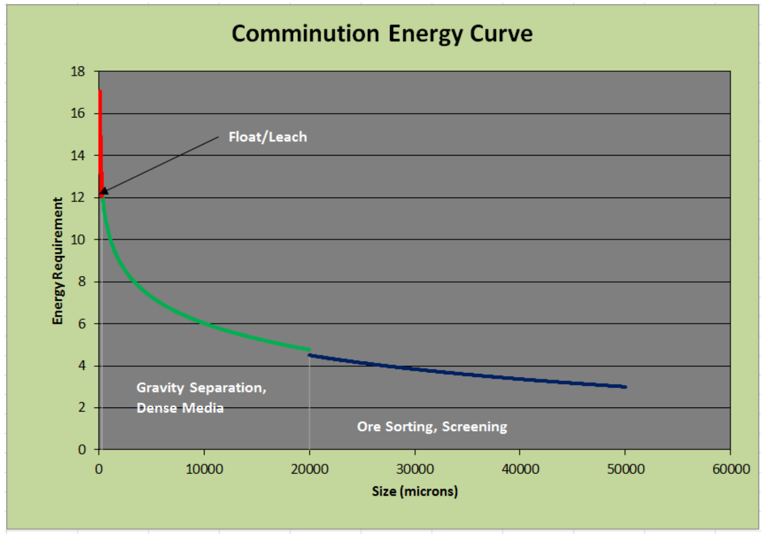

Figure 2 - Energy Curve and Pre-concentration Methods

Waste rejection on an ore that exhibits a 'bimodal' size distribution can be performed by simply employing a screening process. Recent work undertaken at the Telfer Au-Cu mine in Western Australia has demonstrated the potential to pre-concentrate feed grades by using size-by-size screening of run-of-mine ore after blasting and primary crushing, with over 80% of the gold and copper concentrated in less than 40% of the mass below 20 mm (CRCore, 2014).

Similar to the screening process, pre-concentration involving optical and x-ray sorting and the early rejection of waste can be utilised at coarse liberation sizes (20-100 mm). Pre-concentration in this early stage produces a higher grade feed stream which often enables more flexible downstream processing options. Despite screening and optical sorting being desirable options, a problem with pre-concentration at such coarse sizes is that often the valuable mineral is not adequately liberated and extra crushing or grinding is required.

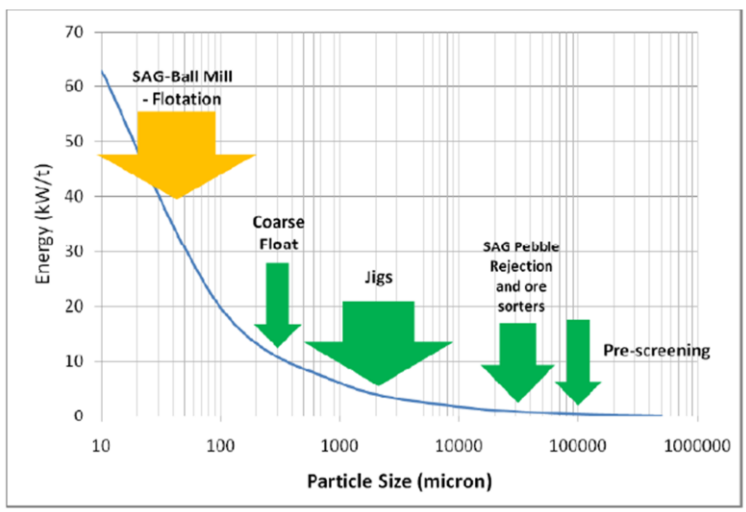

Figure 3 - Pre-concentration methods and size/liberation energy

At finer sizes other pre-concentration methods need to be employed. Jigs, spirals, flash flotation and conventional flotation are all options as the grind size reduces. Gravity concentration utilising jigs can operate over a very wide size range. Jigs are a suitable option from 100 µm up to 25 mm (Figure 3), however optimally operate within +200 µm to 10 mm. This wide range is also relatively low on the 'liberation energy' range (2-10 Kwh/t).

The relationship between pre-concentration and comminution is evident when considering the liberation size and the methods employed. Comminution 'tools' such as High Pressure Grinding Rolls (HPGR) and Vertical Shaft Impactors (VSI) are increasingly being introduced into the industry to take advantage both of their ability to liberate valuable minerals at their coarsest sizes and their low operating costs. The transfer of energy directly from the HPGR rolls to the feed is thought to be more efficient when compared to tumbling mills (Fuerstenau and Abouzeid, 2007) and it liberates sulphide particles and metallic gold along their natural grain boundaries (Koski, et al, 2012). The reduced physical damage to the sulphide surface, low sliming and excellent liberation of coarse sulphides result in a significant improvement during gravity pre-concentration (Dunne, 1996). VSI's are very effective in reducing crushing operating costs and have a unique breakage style. The VSI produces a 'cubic shape' particle and so is considered a 'metallurgical tool' to produce a coarse mineral product ahead of a continuous gravity concentration circuit (Gray, 2014). This offers similar benefits to the HPGR at a lower capital cost.

The relative calculated cost to liberate to P100=500µm is ~US$1.30/tonne using the VSI, compared to US$1.50/tonne for the HPGR (Gray, 2014). Comparing this to a combined SAG and Ball mill circuit, (assuming 15kW/ht @ $0.10kW/hr, media 1kg/t @ $1.20 and liners $0.25/t) the cost is ~US$2.95/tonne. It highlights the viability of both the HPGR and VSI options to provide a more suitable 'feed product' for pre-concentration (Figure 4).

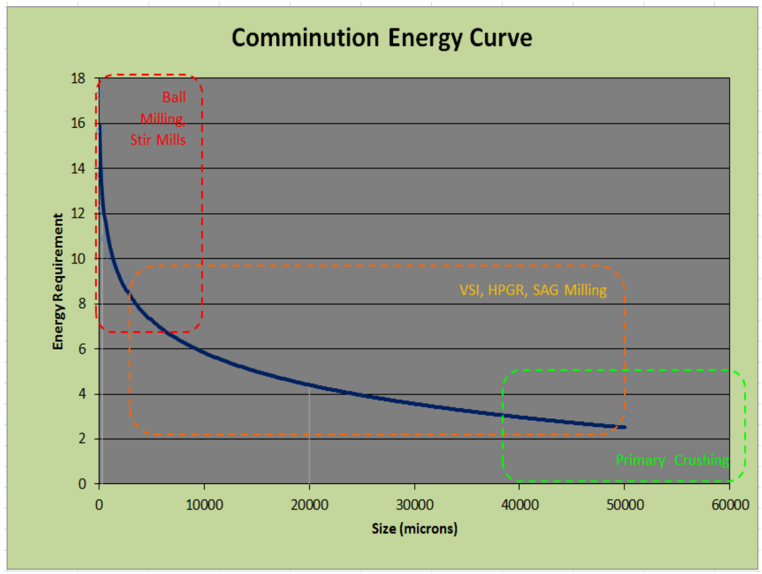

Figure 4 – Energy Curve and Liberation methods

Other factors that need to be considered in choosing a suitable comminution method include the hardness, sulphide content, moisture and clays; these factors can have a significant effect on both HPGRs and VSIs.

Dense Media Separation (DMS) plants are often utilised to concentrate heavies into smaller mass yields. Although providing a 'sharp' cut point and good concentration ratios, dense media separation is often quoted at costing between $1.20-2.00/t ore treated (Cresswell, 2001).

Flotation, is also used as a form of pre-concentration, especially when considering a high yield rougher stage, and has a similar operating cost to DMS. Costs can range between UD$1-2/tonne, (2000tpd @ 2% sulphide) not including the cost of comminution which can be significant (Litz, 1990). Jigs and other continuous gravity machines are very cheap to operate, easy to run and able to cope with variable grades and flow rates. Jigs, although well-known and simple to operate, can sometimes suffer from inefficient partition curves. Spirals also have a very low operating cost; however spiral plants require multiple units to achieve high throughputs (Smit et al, 2012).

Benefits of Pre-concentration

Table 1 outlines a range of benefits that pre-concentration and gangue rejection can provide a project. Not all of them apply simultaneously and not all of them are applicable to each ore type.

1. Increases the overall throughput of an existing plant without installing extra milling capacity or alternatively for a greenfield site the milling circuit and subsequent downstream process can be reduced in size, dramatically reducing the capital costs.
2. Lowers the energy costs, if gangue rejection of waste can be performed on the harder non-metaliferous material.
3. Increases the grade to downstream processing options and in many cases this also increases the efficiency of these processes. In the case of flotation both recovery and grade will improve. Reagent consumption is also likely to be optimised.
4. Reuses the discarded material, if coarse, in other areas of the mine; it also offers benefits in reducing water requirements and easier tailings disposal methods. Backfill plants and co-disposal methods may become more attractive.
5. Reduces reagent contact to tailings lowering cost of disposal. Enables coarse dry stacking of tailings.
6. Makes mining methods easier by allowing more waste to be sent to the ROM with the knowledge that this will be discarded by the pre-concentration process. This can also effectively drop the cut off grades and change the reserve and/or resource calculations.
7. Provides the mine an option to treat marginal ore grades and ore waste dumps if the ore can be upgraded to economic feed grades.
8. Improves start-up cash flows by upgrading ore to prove faster payback times.

Table 1 - Benefits of Pre-concentration

InLine Pressure Jig as a Tool for Pre-concentration

The InLine Pressure Jig (IPJ) is very effective in removing sulphides from milling circuits and is extensively employed in precious metal circuits. It can also be used as a pre-concentrating unit within multiple commodities, including; diamonds, tantalum, zinc, native copper and tin. When used in series within a rougher-scavenger configuration, it is able to recover very large mass yields to concentrate, making it a good option for gangue rejection. The IPJ is able to effectively operate in the three areas of the yield recovery curve outlined in Figure 1.

Its ability to produce a range of mass yields at a low operating cost makes it ideal for pre-concentration. The IPJ's operating cost is calculated at $0.05/tonne treated, including power (4 Kw installed), maintenance and consumables for a typical 100 tph unit (Heins et al, 2003).

The IPJ is fully encapsulated and pressurised, and combines a circular bed with a moveable sieve action. The screen is pulsed by a hydraulic driven shaft to achieve an optimum saw-tooth motion. The separation of the valuable minerals from gangue takes place based on relative density and is continuously discharged. The lighter mineral is discharged over the overflow to tails. Both concentrates and tailings are discharged under pressure (Figure 5).

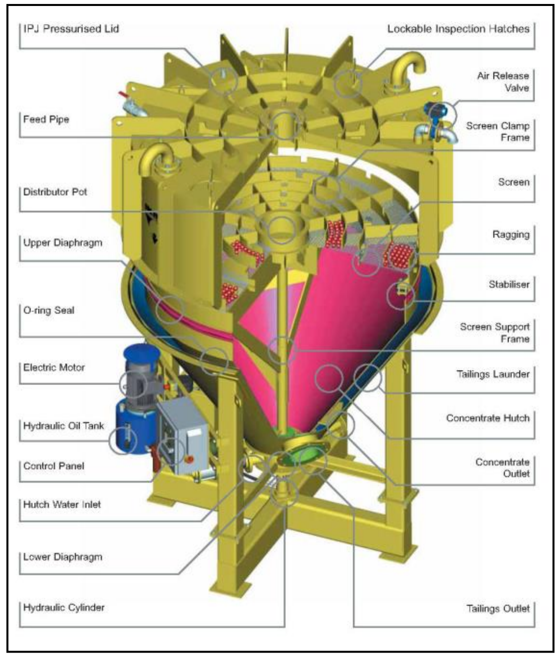

Figure 5 - InLine Pressure Jig

A recently developed IPJ3500 capable of 250tph, opens up the potential to use the IPJ in higher volume applications. A new 750tph (6Mtpa) pre-concentration module design has been proposed for base metal applications in copper, lead and zinc applications.

A robust test protocol for the IPJ has been developed. The process involves testing coarse material (+3-25 mm) in a 'Viking Cone' (Figure 6). Dense media is pumped in closed circuit at a measured density, feed is introduced with the material either reporting to a sinks or floats fraction. Multiple densities are used with the final results producing a partition curve. The finer fractions (-3 mm) are tested using a simple 'shaking table' test procedure and ore is split into a number of specific gravity fractions. The combined data is used to develop a yield/recovery curve. It is also possible to model the amenability of the IPJ using typical DMS or heavy liquid data and applying an Ep value.

Figure 6 - Viking Cone Test Rig

The test data and results will be different, not only for different liberation sizes but also for different comminution methods. Ball mills can often flatten free gold or overgrind minerals such as lead and tantalum. Preparation using grinding mills may reduce the potential for pre-concentration so pilot scale HPGRs and VSIs are utilised within the laboratory procedure to prepare the feed samples.

IPJ Pre-concentration Applications and Test Work

Ballarat Gold Mine – Lion Gold

The Ballarat Goldfields ore body contains quartz veins with coarse gold and sulphides (Figure 7). Initial gravity tests identified that liberation and recovery could be achieved at +600 µm. The results indicated that the ore could be concentrated into 5-10% of the mass at a grind of P80=600 µm (Figure 8). Interestingly, the potential for pre-concentration via gravity techniques diminished as the ore was ground finer. The finer grinding of the ore had a large impact on the sulphide size distribution due to the ore's more friable nature and thus overgrinding of the sulphide resulted in poorer recoveries. Operational data indicated that high sulphur and subsequent gold recoveries could also be achieved at P80=1 mm.

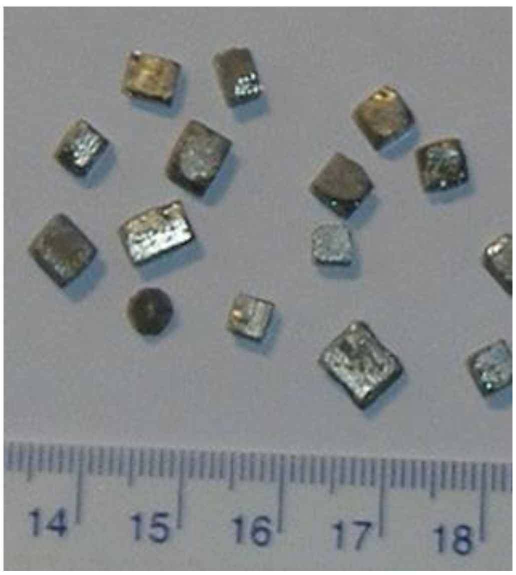

Figure 7 - Coarse Sulphide Recovered in the IPJ

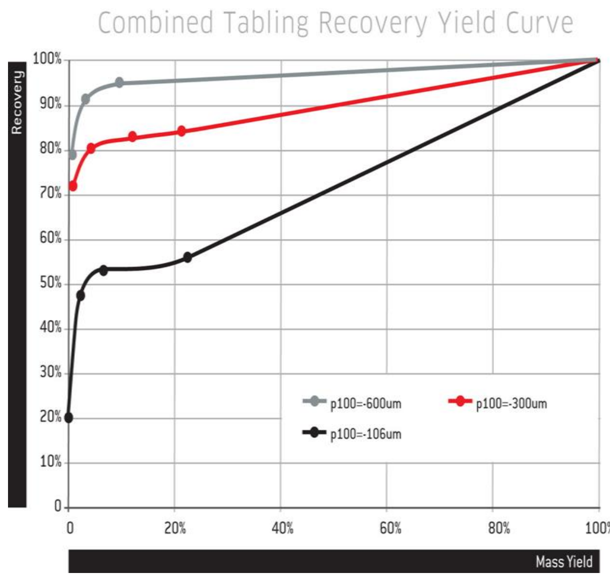

Figure 8 - Yield/Recovery Curve at 106, 300 and 600um

A flowsheet was developed using fine crushing, in this case a VSI, to liberate the sulphides down to one mm. The VSI allowed the sulphides to stay 'cubic' in shape by breakage along natural grain boundaries; this enhanced the recovery achievable using the IPJ. The single pass break and recover concept of the flow sheet takes advantage of coarse liberation, without the overgrinding that would typically occur in mills.

The process flowsheet utilised 6 x IPJ2400s (100 tph) within a rougher and scavenger configuration to recover over 90% of the gold and sulphur into 5-10% of the feed mass. A BCC (batch centrifugal concentrator) was used to scavenge some of the fine free gold (<75um) that was not within the recoverable range of the IPJ.

As a result the mine is able to run as a 'gravity only' circuit and does not employ a milling circuit. This is effectively a gold pre-concentration plant that provides very large operational cost benefits to the project. The final concentrate representing 5-10% of the mass is reground and leached under intensive cyanidation conditions within an InLine Leach Reactor (ILR) circuit.

Pirquitas Mine – Silver Standard

The Pirquitas mine, a Silver Standard operation located in Jujuy, Argentina, is a poly-metallic mine with silver, zinc and tin as the primary minerals. Due to the highly variable grades within the ore body, pre-concentration was considered in order to meet the production required to develop the mine. Initial test work looked at pre-concentration of the ore from a cone crushed product at a size distribution of P100=-11 mm. The test work indicated that +95% of the silver, tin and zinc could be recovered into a mass yield of ~50% at a crush size of -11 mm (Figure 9).

The ore has a natural tendency to upgrade into the fines fraction. ROM-crushed material is screened at 2 mm with this fraction representing ~25% of the ore directed straight to the ball mill at a 2:1 upgrade. The remaining material (+2 mm -11 mm) is subjected to pre-concentration.

A testwork program was undertaken by using a Viking Cone test protocol. Subsequent work was completed independently to confirm the results.

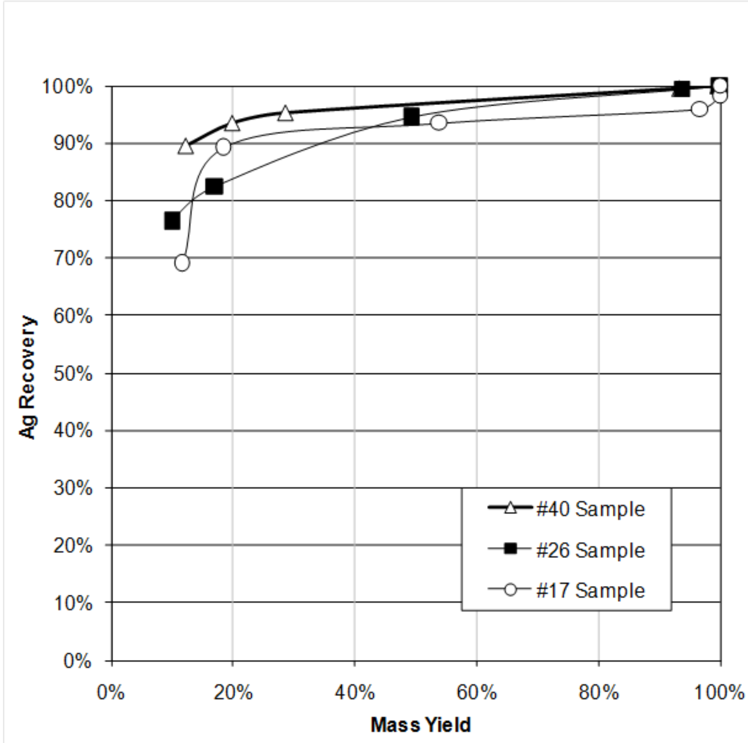

Figure 7 - Silver Recovery Testwork Data

Silver Standard developed a modular style pre-concentration plant treating 270 t/h, using 6 x IPJ2400s with a rougher and scavenger configuration to pull a 50% mass yield to concentrate.

The IPJ concentrate is dewatered and combined with the -2 mm material for downstream milling. The IPJ tailings (+2 -11 mm) are dewatered and then stacked as a coarse, semi-dry product as final tails. As a result a +33% reduction of ore treated was achieved providing a total upgrade of 1.5:1 to the milling circuit.

Plant performance data correlated very well to the test work data. Not only has the mine experienced an increase in grade and metal units to the mill circuit but other advantages including the improvement in flotation efficiency. Advantages included increased metal production, better flotation recovery and increase to concentrate grades (Gray, et al 2011).

Rosh Pinah – Namibia

Testwork was performed on samples from Glencore's Rosh Pinah lead and zinc mine in South Africa to determine the coarsest possible liberation size suitable for pre-concentration. The test work, which combined Viking and table tests, indicated that on size fractions between +1.18 mm and -25 mm, 90% of the Pb and Zn could be recovered into 65% of the mass, a good response considering the extremely wide particle size range treated (Figure 10).

This test work demonstrates a typical gangue rejection circuit characteristic with the masses required to go to sinks being very high. Liberation improves between 8-16 mm and the comminution process produces larger quantities of valuable mineral in the finer fraction, suggesting that the valuable mineral is friable.

A proposed circuit would target 60 – 70% mass yields to achieve recoveries in the low to mid 90's for all the valuable metals.

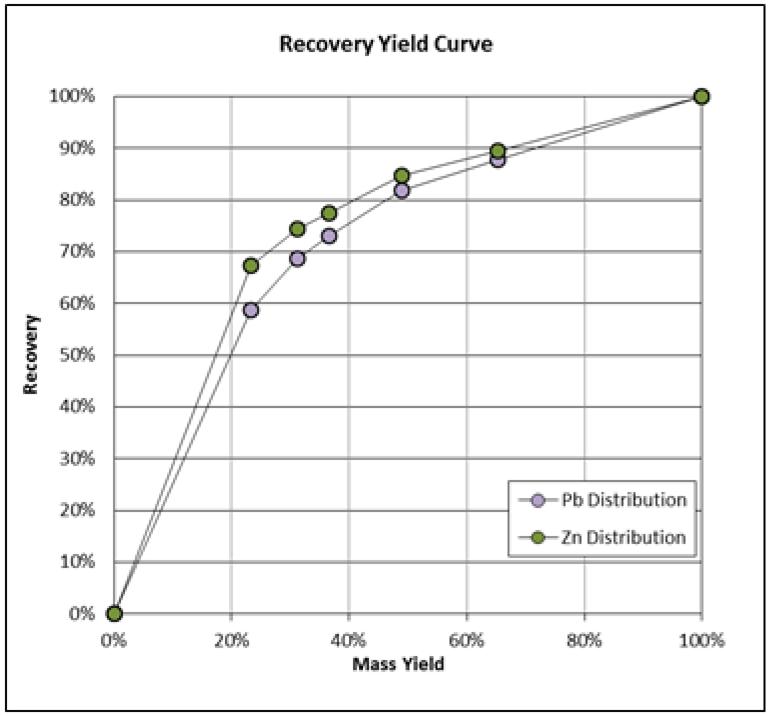

Figure 8 - Grade Recovery Curve for +1.18mm -25mm Pb/Zn

Mineraçao Caraiba – Brazil

Further to the test work in Namibia, Glencore also tested the pre-concentration of copper on several of their ore types at Mineracao Caraiba mine in Brazil.

The tests were performed on a cone crushed sample at P100= -11 mm. The tests were also performed at different size fractions and a combined yield recovery curve was produced. Results indicated that 90% of the copper could be recovered into 66% of the mass. The upgrade ratio is effectively 1.4:1 improving the head grade from 1.6% to 2.2% Cu (Figures 11 and 12).

Further tests indicated that the best results occurred in the +3-6 mm fraction, providing an option to liberate using the VSI and optimise the recovery. A potential flowsheet involved jigging two separate size fractions within a closed circuit and treating the oversize through a VSI crusher and IPJ before exiting the circuit at -3 mm.

While the test work is encouraging there is still an argument that the losses could be reduced with a fine grind; but at what capital and operating costs? It is likely that a typical concentrator including fine grinding and milling can improve recovery and may be a viable option; however access to finance is often difficult for companies to obtain. Pre-concentration may offer companies an option to develop deposits at a lower capital cost and maximise the economic returns.

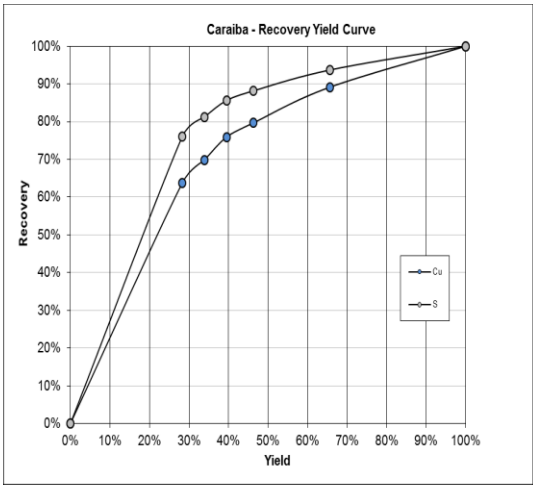

Figure 11- Recovery Yield Curve (-11mm)

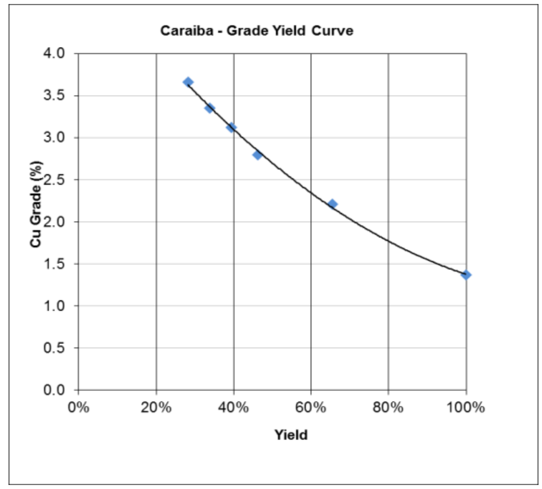

Figure 12 - Grade Yield Curve (-11mm)

Potential for Mine Planning

Up to this stage the benefits derived from the case studies have all been based around processing or metallurgy. Pre-concentration also has the potential to be utilised at the beginning of the mine development process.

If the ore is identified as being amenable to pre-concentration, especially at a coarse liberation size, this will effectively increase the grade of the mill feed, drop the operating cost or increase available tonnages for downstream processing. Mining engineers are able to transfer this data into mining models to optimise the pit and mine design on a completely new set of variables.

The increase in feed grades achievable using pre-concentration effectively reduces the cut off grades that the mining engineers can use in the mining models. By dropping the cut-off grade the number of tonnes of a resource can be increased and subsequently the mass of metal within the ore body can be increased. Care should be taken to reduce the fines produced in the mining process in order to optimise the mass fed to the pre-concentration stage.

A typical grade tonnage curve (Figure 14) indicates that if the cut-off grade can be reduced, due to a pre-concentration process being utilised within the plant design, then the ounces produced and the tonnes (mine life) will increase. This may have a major effect on the economics of the mine.

Pre-concentration also has the potential for extra dilution to be mined at the design cut-off grade, potentially simplifying mining methods. It also may enable a project to 'high grade' initial feed to a downstream milling process to improve cash flow (Smit et al, 2009).

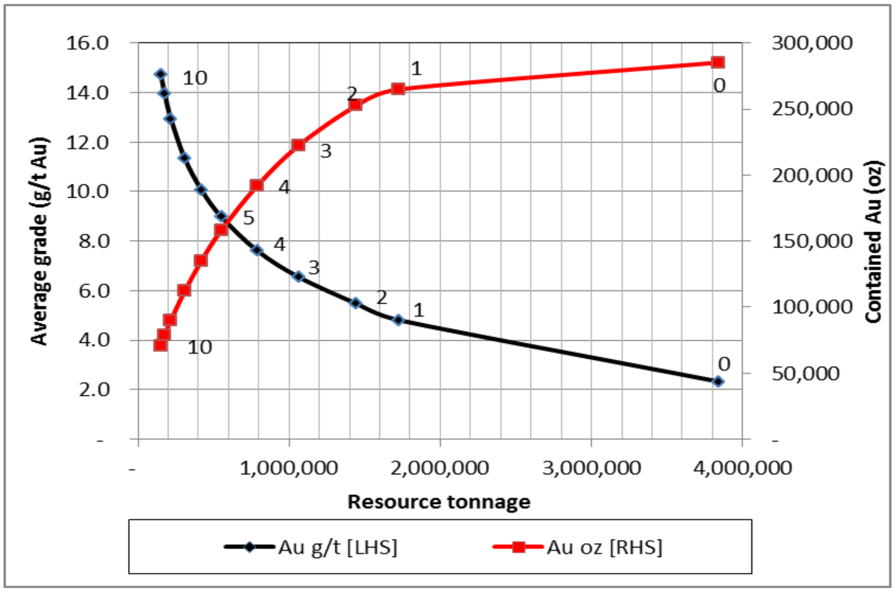

Figure 9 - Typical Grade-Tonnage Graph

Conclusions

Pre-concentration is a process flowsheet option that deserves more attention because it offers a range of very compelling operational benefits. The 'tools' are already readily available and consideration to alternative process flowsheet design needs to be insisted upon by mine owners and investors alike. The old processing paradigms need to be challenged for the industry to remain sustainable.

Each deposit and commodity has its own issues and drivers. Pre-concentration provides options to reduce power, in effect dropping operating costs and, as a result, make low-grade ore deposits economic. It offers a potential sustainable process flowsheet option for an industry operating within a fluctuating environment.

There are various pre-concentration options that can be utilised, each providing its own benefits and suitability. The IPJ is one pre-concentration tool that can provide a number of the benefits outlined; it operates over a wide range of mass yields, tonnages and size distributions, and, most importantly, at a lower operating cost.

Operations currently utilising the IPJ are running very successfully, with the modules reaching their designed recoveries and availabilities. The potential of pre-concentration over a wide range of applications is clear when looking at the test work results achieved to date.

The testing procedures to check the amenability of an ore are well developed and can be used over wide size distributions. The industry accepts the test work procedures and data, and the data can be easily modelled producing industry standard partition curves and mass-yield graphs.

Pre-concentration can be employed not only as a powerful metallurgical tool but also upstream in the mining process to optimise mine plans and in the development of low grade ore bodies. The potential to integrate the metallurgical results back into the mining plan should be considered by every operation as a process option.

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