# ECONOMIC RECOVERY AND UPGRADE OF METALS FROM MIDDLING AND TAILING STREAMS

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## ABSTRACT

As mine head grades decline and orebodies become more complex, traditional mineral processing techniques and flowsheets to achieve saleable concentrate become more difficult to design and construct. Mines with lower quality concentrates or concentrates with penalty elements are particular under threat. The economics of these operations are far more susceptible to metal price, concentrate treatment terms and the availability of other, cleaner concentrates. Additional value may be realised for these orebodies through improved recovery by producing a low grade middling concentrate for further processing, in conjunction with a saleable concentrate.

The most cost effective way to reduce impurity levels is to do so as early as possible in the mining value chain. Technologies such as fine grinding and fine particle flotation are well established as effective methods for impurity rejection in mineral processing. What is normally overlooked is how a hydrometallurgical process could also be integrated in the overall flowsheet to achieve higher overall recovery at the mill. In the base metals environment, this is mainly because hydrometallurgical processes are associated with production of metal or use of expensive and toxic precipitating agents once the minerals of interest are solubilised. These processes can be very expensive, particularly with rising power costs and poor economies of scale in capital costs associated with low production rates from middling streams.

Glencore Technology (GT) has recent experience in the treatment of middling and low grade concentrate streams as well as tailings streams to compliment a concentrator flowsheet in a refractory gold and base metals setting. The value proposition is the isolation of a low grade middlings concentrate from the primary circuit or the tailings stream for upgrading to an intermediate product with an equal or higher grade than the primary concentrate to allow blending for sale. This allows plants to operate on a more favourable part grade-recovery curve while avoiding the expense of metal production. For existing operations this is particularly attractive since it can be added on with no process interruptions.

Two case studies are examined showing flowsheets and costings to arrive at the value proposition of the GT low grade treatment flowsheet.

## KEYWORDS

**Albion, IsaMill, Jameson cell, Glencore**

## INTRODUCTION

One significant challenge facing the gold and base metals mining industries is the globally observed trend of reducing mined head grades. This challenge is faced with existing operating assets and presents a significant hurdle in the justification for new projects. Figure 1 shows global trends in mined head grade from the mid 1800's to 2010 (CSIRO 2015).

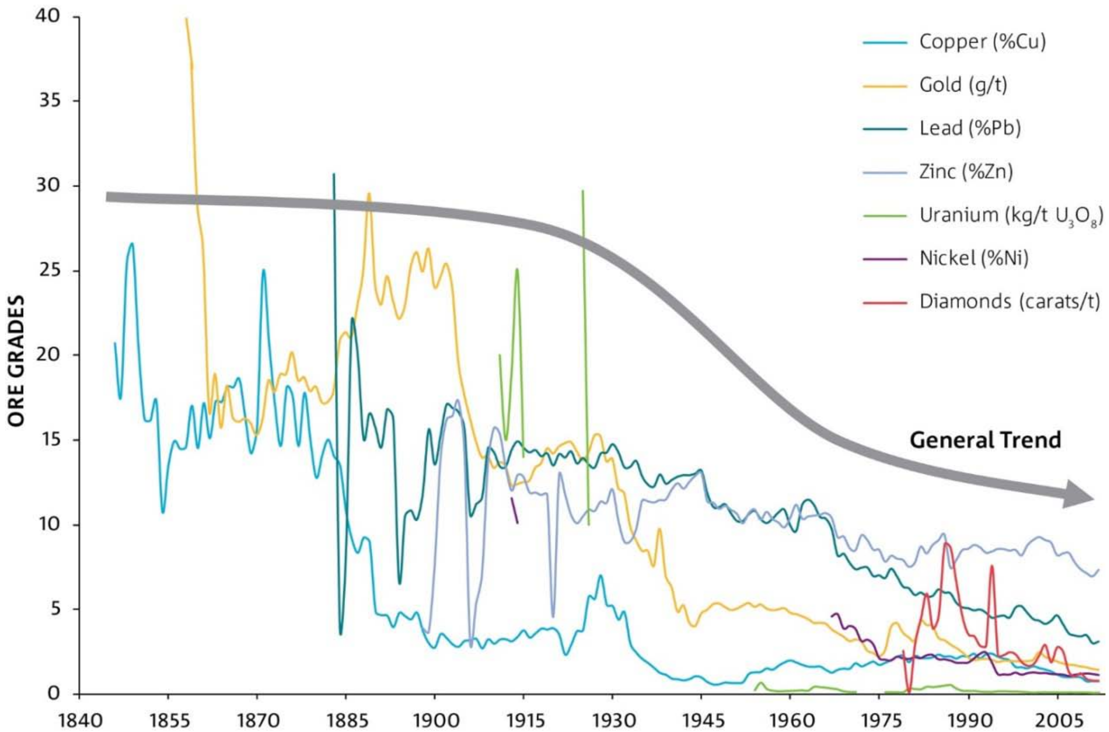


Figure 1 – Mined head grades for base metals and gold.

New projects or orebodies within existing operations, where reasonably good head grades can be maintained, tend to defy this globally observed trend through a corresponding increase in geological and metallurgical complexity. This is important for miners because metal input can be maintained without increasing milling rates however for a given flowsheet the quantity and quality of metal outputs will be compromised. While throughput of high-grade, complex orebodies can maintain input metal units they may not achieve target grade or recovery, and may even introduce penalty elements to the concentrate (Munro 2015), effecting economic viability.

By way of example, challenges faced with complex ore treatment in a flotation concentrator where the concentrate would be directed to a smelter include:

- Inability to find an economic operating point on the grade recovery curve such that both grade or recovery is not achieved for economic sale to a smelter
- Sacrificing the final product concentrate grade by inclusion of a middling concentrate that serves to increase overall recovery but negatively impacts grade and introducing penalty elements
- Inability to separate the economic minerals in an orebody rendering the production of a bulk concentrate with poor terms of sale to a smelter

Figure 2 illustrates the general trend of how grade versus recovery curves have become less defined as recovery increases.

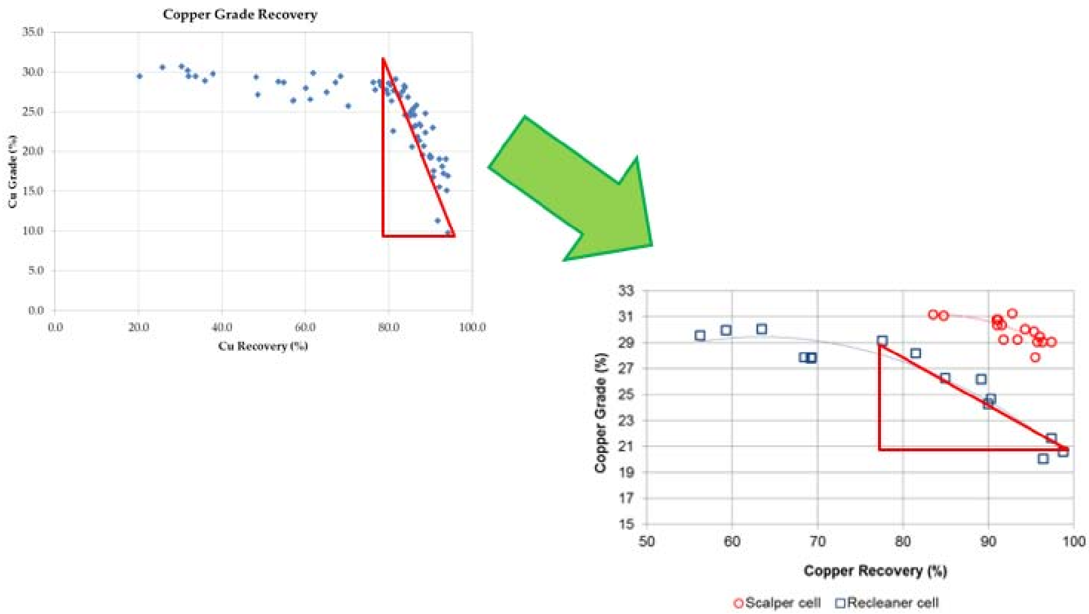


Figure 2 – Less defined grade recovery curves lead to lower concentrate grade to achieve target recovery

In general, the gradient of the grade recovery curve has decreased resulting in a non-optimal operating position on the curve. This is a reflection of the general increasing complexity of ore to maintain mined head grade. The reason the ore complexity is reflected in Figure 2 is that minerals become more difficult to separate from one another and are recovered together, (Young 1997).

Certain ore-types cannot be upgraded with mineral processing techniques to produce a concentrate for downstream treatment in smelters. One example of these ores are the highly weathered or oxidised ores that are treated via heap leaching or whole ore leaching for copper and cobalt recovery. This processing method suits certain ore types and where sufficient infrastructure can be established at low cost. For example, heap leachable ore, requires ore with minimum levels of competency and permeability when it is stacked. The mineralisation must be such, that it is readily acid leached, with sufficiently low net acid consumption to be economic. A separate plant is then required to recover the copper once leached into solution, and then solvent extraction and electro-winning plants are required to produce saleable copper cathode. This flowsheet is conditional on the availability of reliable and relatively cheap power.

Ore types that don't fit neatly into conventional flotation or heap leaching flowsheets have traditionally been relegated to waste. These ores are generally referred to as Complex Ores. Increasingly, these ore types can no longer be viewed as waste due to the contained metal content and high costs of pre-stripping this material where it overlies more economic deposits. Often these pre-stripping costs can make a project uneconomic unless metal can be recovered from this waste material.

**Treatment of Complex Ores Through the Concentrator**

During the mining boom of 2004 to 2009 the challenges of increasing metal prices coupled with the increasingly long lead times to bring a project to production led to mining companies adopting a strategy of a standard concentrator design (Combes 2011). The standard concentrator would allow significant improvement in the design and procurement phases of a project, and allow projects to be implemented faster to take advantage of rising metal prices. A common circuit used in a standard concentrator design is reflected in a simplified flowsheet in Figure 3.

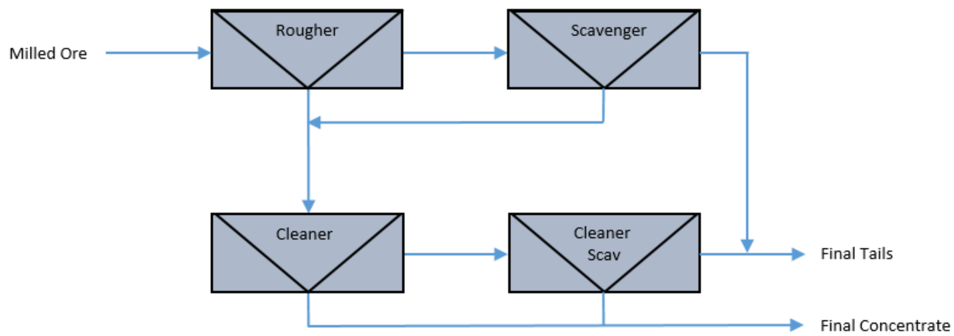


Figure 3 – Conceptual flotation plant

The standard concentrator is a valid concept where a number of concentrators are envisaged to be built across projects with identical geological and metallurgical characteristics. The standard concentrator is still an excellent concept where there will be some variation between projects where some slight modification to the standard concentrator can be tolerated. When processing complex ores, however, where a single deposit may have multiple complex metallurgical domains, it becomes very difficult to design a single flowsheet that can treat all ore types while maximising economic performance.

Figure 2 shows that treatment of ore with increasing complexity in a set flowsheet will result in a compromise between recovery and grade or contamination of the final concentrate with deleterious metals and gangue. This can significantly impact the economics of a mining operation, (Munro 2015).

## Modification of the Concentrator for Complex Ores

Modifications made from the conventional flowsheet for the treatment of complex ores generally comprises two approaches. The first is increasing the extent of grinding. This is based on the premise that when grade or recovery of an economic mineral is not obtained it is not liberated from gangue and does not have exposed surfaces to float. While there is some focus on the primary grind, usually when ore complexity increases, concentrate re-grinding, using a fine grinding mill such as the IsaMill™ is included in the circuit (Burford 2007). This style of flowsheet is reflected in Figure 4.

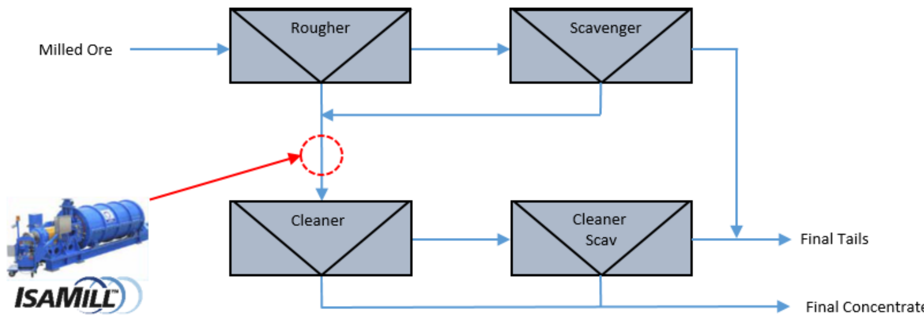


Figure 4 – Modification of the conventional flowsheet for fine grinding

The addition of concentrate regrinding to a flotation circuit as shown in Figure 4 is based entirely on increasing liberation. Once the minerals are liberated they must then be floated which can create further issues as finer particles have slower flotation kinetics compared to courser particles, and require more residence time to achieve the same recovery.

The second modification to the standard flowsheet commonly used is an increase of residence time through the installation of more flotation capacity or modification of the circuit configuration as reflected in Figure 5.

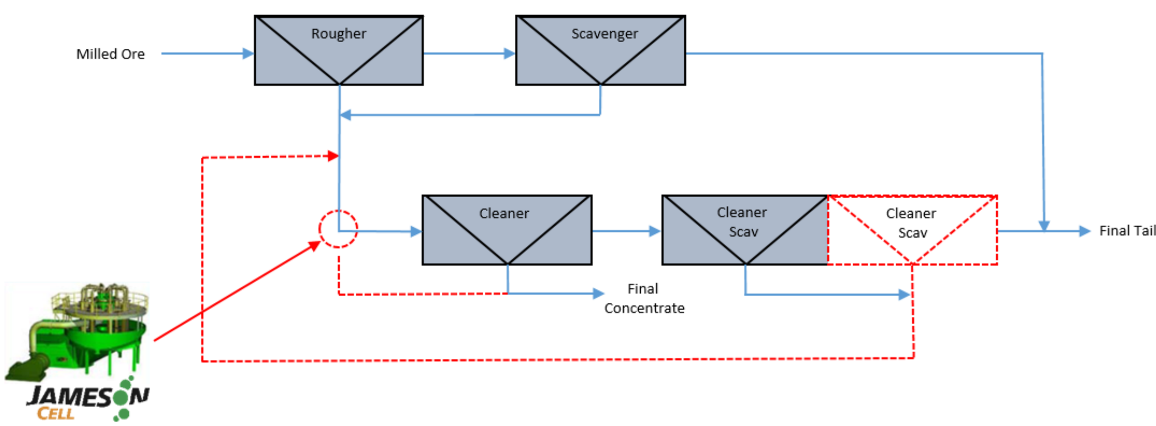


Figure 5 – Modification of the conventional flowsheet for circuit configuration or longer residence time

For fine particle flotation, a properly designed circuit may have the benefits of reducing recirculating loads, reducing reagent demand, as well as improved metallurgy. Examples such as McArthur River Mines routinely produce average zinc concentrate less than 10um in size, (Pease 2004). Alternatively, different flotation equipment can be added to the flowsheet such as the Jameson Cell which is well documented in the literature and proven in the field for improved fine particle flotation compared to a mechanical cell (Young 2006).

The basic modifications to the conventional flotation flowsheet are all validated when they result in improvements in the grade and recovery of the valuable metals to economic levels. Some extremely complex ore types, however, will still not respond fully to such modifications and there is a need for a more encompassing approach.

A further complication occurs when designing a new project or modifying an existing operation for the treatment of a more complex ore, where the circuit design is based on the treatment of the most complex metallurgical domain in the orebody. This leads to circuit complexity that is not needed for a large percentage of the ore treated. Due to the mining sequence and certain ore types not stockpiling well, the more complex ores will not be treated in discrete campaigns. The result can be the installation of excess flotation and re-grinding capacity that is not utilised all of the time, resulting in an inefficient use of capital.

## GT Process for Treatment of Complex Ores

Over the past 20 years there have been significant advances in technology and equipment in the fields of mineral processing and hydrometallurgy in the mining industry. GT has been at the forefront of these advances with the following technologies:

- IsaMill™ – A high efficiency fine grinding technology in a horizontally stirred mill utilising inert ceramic media
- Jameson Cell™ – A high intensity pneumatic flotation machine with no moving parts generating fine bubbles
- Albion Process™ – Fine grinding followed by atmospheric leaching technology for refractory and base metals concentrates, including low cost recovery of base metals from solution to high grade concentrates with low grade reagents

The Albion Process™ is a patented technology developed by Glencore in 1994. The Albion Process™ consists of two key steps. The first step is ultrafine grinding of a sulphide concentrate, using Glencore Technology's IsaMill™, to particle sizes in the range 80 % passing 10 – 15 microns. The second step is an oxidative leach of the finely ground sulphides at atmospheric pressure to breakdown the sulphide matrix and liberate base and precious metals prior to metal recovery. There are currently five Albion Process™ plants operating globally in base and precious metals duties.

As a response to the increasing ore complexity, GT proposes a flowsheet that is a combination of these recent advances in mineral processing and hydrometallurgy processes. A conventional flotation flowsheet is still adopted when designing for new projects or existing operations encountering increasing ore complexity but with the addition of a hydrometallurgical processing step to deal with the low grade concentrates bled from the flotation circuit to smooth our variations in plant operation. One version of the concept is illustrated in Figure 6.

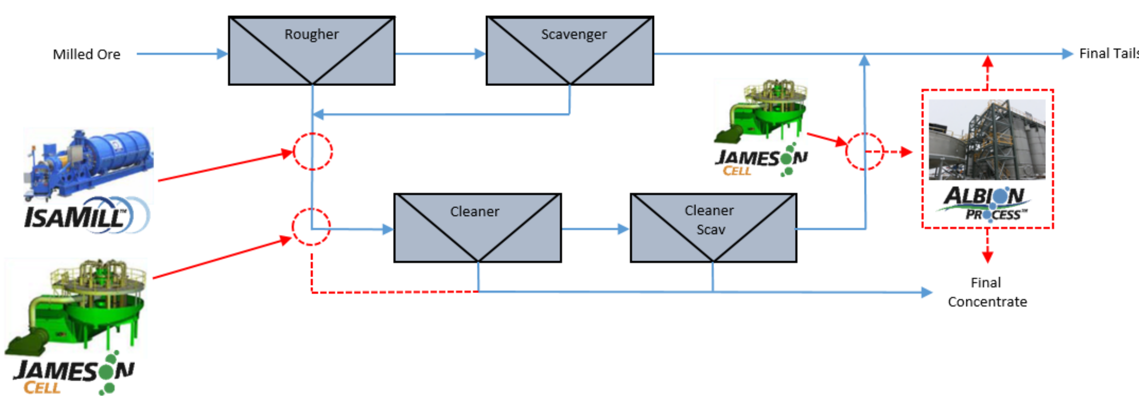


Figure 6 – GT concept for complex ore treatment

Figure 6 shows how the conventional flowsheet may be modified in an example where the concentrate reporting to the cleaner circuit is treated through an IsaMill™ and then a Jameson Cell prior to the Cleaner bank, obtaining grade, however the recovery is not at target levels meaning that further cleaning must be employed to achieve recovery. The Cleaner and Cleaner Scavenger banks provide further recovery, however the combined concentrate is below target, resulting in an overall dilution of the concentrate grade. In the modified flowsheet, a Jameson cell treats the Cleaner Scav tailings to recover a low grade concentrate. This low grade concentrate is bled from the circuit and processed in a dedicated hydrometallurgical plant. Complex middling particles recovered in the Jameson cell are removed from the circuit and are not recirculated through the flotation plant.

The fine grinding stage prior to the cleaning circuit allows for high pull rates from the Rougher and Scavenger, improving primary circuit recovery. The use of the Jameson Cell allows for good quality concentrate to be produced after fine grinding, with the wash water on the cell reducing the recovery of non-gangue particles.

The operation of the Cleaner and the Cleaner Scav enables the operation to balance the grade and recovery to be achieved from the circuit. Too high a recovery from this circuit recovers not only wanted liberated valuable mineral, but also the locked and complex particles towards the end of the circuit, unnecessarily diluting the concentrate. There is also the possibility of penalty elements that could be recovered in the concentrate with too high recovery rates. Therefore recovery needs to be controlled to prevent these particles from being recovered and left in the Cleaner Scav tails.

The Cleaner Scav tails are treated with a Jameson Cell, further increasing circuit recovery, but targeting complex particles that cannot be collected to concentrate in their current state due to the low concentration of valuable minerals.

The concentrate collected from the Jameson Cell doesn't need to be high grade to be economically treated through the Albion Process™. Grades down to 5% copper in concentrate have found to be economic. One issue with including the Albion Process™ in the flowsheet is how to recover the metals that are leached into solution at low cost. This is achieved through a process developed by GT for zinc, copper, nickel and cobalt where either lime or limestone is used to continuously precipitate the base metals at controlled pH. A common problem with this type of precipitation process is the co-precipitation of gypsum. GT has developed procedures to overcome this issue by carefully controlling the process conditions such that the gypsum grows to particle sizes significantly coarser than the base metal oxides, and can be separated by hydrocyclone, as illustrated in Figure 7.

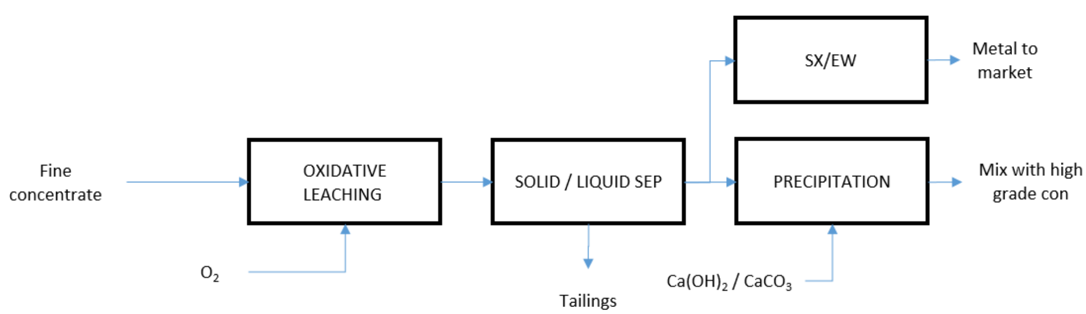


Figure 7 – Integration of the Albion Process™ into the mineral processing flowsheet

When applied to a copper circuit, the feed material to the Albion Process™ would be a low grade 5% copper middling concentrate which is then leached to solution and precipitated as a 45% copper oxide concentrate. This high grade intermediate can then be sold for use in a range of industries, or alternatively blended with the final concentrate product for sale.

## CASE STUDIES FOR THE GT PROCESS

Two case studies are presented to illustrate the concept and high level information has been provided on the incremental improvement that can be achieved by incorporating the Albion Process™ into the concentrator flowsheet for processing a low grade middling stream.

### Case 1 – Copper NW Queensland

Case 1 relates to an opportunity for brownfields expansion of mining and concentrator operations at a mine in North Queensland. The ore complexity at the operation will increase for a short duration due to the need to mine through mainly transitional/weathered ore zones with a variable base of oxidation, resulting in some primary zones intermixed with the transitional ores. The variation in the contact zone between the transitional and primary ores is such that the ores cannot be separated and must be treated together. They are in a quantity such that the contained metal units from both transitional and primary ore must be recovered to justify the overall project.

The main copper bearing minerals comprise native copper, chalcopyrite and chalcocite with minor chrysocolla and malachite. The sulphide gangue comprises mainly pyrite with minor pyrrhotite, galena and sphalerite.

The ore presented to the process typically grades 1 to 2% copper with varying mineralogy. Within the feed some of the ore types can be recovered to a concentrate grading greater than 25% copper, however for the pure transitional ores, the maximum copper concentrate grade is only 5% copper. The transitional concentrates, however, contain predominantly leachable minerals, and lend themselves to be separated to a middlings stream for separate hydrometallurgical processing. A simplified flowsheet is illustrated in Figure 8.

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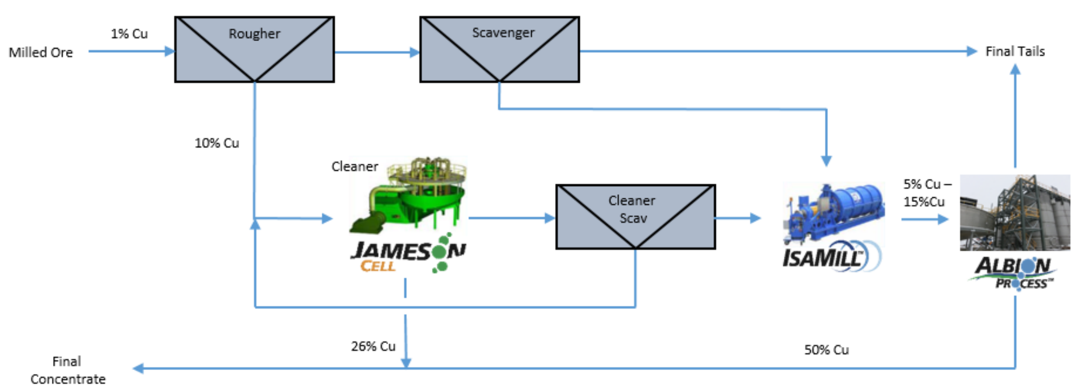


Figure 8 – Copper treatment flowsheet

The simplified flowsheet in Figure 8 indicates a pathway for liberated copper sulphide mineralogy to report to a final cleaner concentrate to achieve on specification concentrate at +26% copper grade for sale. The material that is not amenable to upgrading, diluted by both sulphide and non-sulphide gangue is recovered in both the scavenger concentrate and the cleaner tailings as a 5% Cu middling concentrate that is treated through the Albion Process™. Even at low feed grades the hydrometallurgy treatment option is economical since the final intermediate copper oxide produced grades approximately 50% copper and overall circuit grade and recovery are maximised.

The mineral processing and hydrometallurgy flowsheet adds between 4% to 30% copper recovery at target grade depending on what material is treated. The project allows access to a further 6.0 Mt of high grade primary ore. The treatment of the transitional cap alone has an IRR of approximately 25%.

**Case 2 – Zinc NW Queensland**

This application of the GT flowsheet to zinc processing is treatment of historical zinc tailings. It was acknowledged that significant zinc was contained in the tailings but when the tailings were re-floated a zinc grade of around 10% had to be accepted for any economic recovery levels due to both sulphide and non-sulphide gangue. A number of hydrometallurgy flowsheet options were considered to treat the low grade concentrate, however these options were marginal economically due to the high cost of installing expensive processing equipment to recover the final zinc metal product. The GT approach overcame these economic and technical limitations. A simplified flowsheet is illustrated in Figure 9.

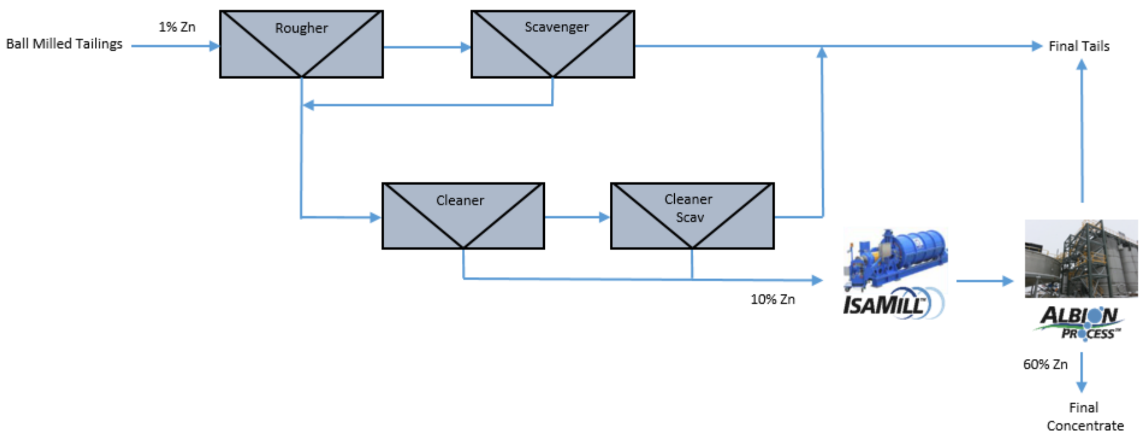


Figure 9 – Zinc treatment flowsheet

The flotation tailings can be re-floated in a conventional flowsheet to produce a 10% zinc concentrate at 90% recovery. The resulting concentrate is fed to an IsaMill™ for grinding to 80% passing 20 micron or below and then to the Albion Process™ oxidative leach for the extraction of zinc. The oxidative leach achieves zinc recoveries of up to 99.5%. Glencore has installed two Albion Process™ plants to recover zinc from a bulk concentrate, in Spain and Germany, and has experience in the design of these plants (Hourn 2012).

Once in solution, rather than producing metal, the GT precipitation process was used with either lime or limestone to produce a zinc oxide at a grade between 50 to 60% zinc. Strategically, since most zinc roast-leach-electrowinning plants are limited at the roaster, such a zinc product can be treated by conventional zinc refineries to maximise cellhouse capacity or operate during roaster downtime.

The plant was sized to produce 100ktpa contained zinc metal but could be easily scaled down if required. The project IRR was 30%.

## CONCLUSION

GT has developed novel flowsheet configurations for the treatment of complex ores through minor modification to conventional flowsheets with minimal process disruption and integration with hydrometallurgy unit operations. The flowsheets presented are just examples and many other variations are possible.

In the mining value chain, value can be most easily added when complexity in ores can be overcome at the earliest part of the chain as practicable. This starts in the mine with grade control, understanding metallurgical domain definition and optimising blast patterns. In the mineral processing sphere this can start with screening and dense medium separation through to grind size and reagent use. In extractive metallurgy this can mean blending with different feeds, additional plant and equipment through to by-product waste disposal. The final product is sold in the market relative to the product quality of other producers. The authors recognise that most value can be added through addressing complex ore treatment as early as possible in the value chain and this paper focuses on blending hydrometallurgical techniques with minerals processing to address ore complexity in the concentrator.

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