Appendix H

Gold processing options

REGIS
RESOURCES LTD

MCPHILLAMYS GOLD PROJECT

GOLD PROCESSING OPTIONS

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1. INTRODUCTION

The McPhillamys Gold Project Development Application (DA) and Environmental Impact Statement (EIS), which was submitted to the Department of Planning, Industry and Environment in July 2019, received submissions from regulators, interest groups and the community.

The EIS included an explanation as to why the Carbon in Leach (CIL) processing option was selected for the project. The explanation was technically based and was accompanied by a detailed risk assessment.

Meetings held with the NSW Resources Regulator and the NSW Environment Protection Authority (EPA) throughout the submissions phase highlighted a need for additional explanation at a less technical level so that assessors who were less familiar with the varying processing options could better understand the explanations in the EIS. The Belubula Headwaters Protection Group in its submission on the project also questioned if alternative methods to cyanide have been explored, such as thiosulphate.

This report therefore aims to articulate the reasons, with simple explanations of technical jargon, why CIL gold processing was selected for the McPhillamys Gold Project.

There are a number of processing options that can be used for the extraction of gold from an ore deposit, however not all of those options are either compliant from a health, safety and environmental standpoint, or commercially viable. Each processing option, compliant or not, is discussed in detail in the following paragraphs.

It should be noted at this point that only two types of processing options are generally used in larger scale commercial operations in what are considered to be first world countries. These are cyanide leaching and flotation.

2. CYANIDE LEACHING

Currently within the gold mining industry, cyanide (CN) is the most commonly used chemical in the economic recovery of gold.

Cyanide has been utilised for over 100 years. Approximately 1.1 million tonnes of cyanide is produced annually worldwide, with 6% utilised for mining. The other 94% is utilised in industrial applications, such as the production of nylon, plastics, adhesives, fire retardants, cosmetics and as an anti-caking agent in salt.

Figure 1 depicts the annual cyanide consumption breakdown.

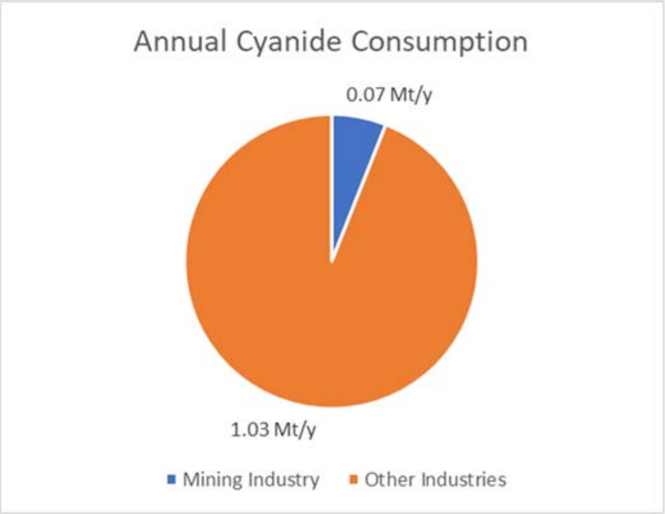

Figure 1 - Hydrogen Cyanide Use - Globally[1]

Cyanide, under typical leaching conditions is reactive and has an affinity for gold which means that gold is preferentially leached first before the cyanide then complexes (or associates) with other metals such as copper, silver, zinc and iron.

In simple terms, this means that gold is very difficult to dissolve and there are only a handful of chemicals that can actually dissolve it, and all of these generally need exacting conditions, which are not always easy to maintain on a large scale. Some of those chemicals can only for now at least, successfully dissolve gold in a laboratory, or on a small scale, for example in a pilot plant.

The metal cyanide complexes formed during the gold leaching process are quite stable and low levels of cyanide salt (200 – 500 ppm) are required. As a comparison, the salt level of a typical home pool is normally around 5,000ppm and sea water is around 35,000ppm.

Those reagents, or chemicals, that can dissolve gold generally need a lot of oxygen (or an oxidant) to assist in the leaching or dissolving process.

The technical reaction for the leaching of gold with cyanide is as follows:

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4Na[Au(CN)_2] + 4NaOH$$

In the reaction shown, Au stands for gold, Na stands for sodium and CN represents a combination of carbon and nitrogen, or cyanide, and with sodium attached, represents sodium cyanide. More familiar to most people are the O_2, which stands for oxygen and H_2O, which stands for water.

When the four are combined in the correct ratio, then sodium gold cyanide ($Na[Au(CN)_2]$) is formed along with sodium hydroxide (NaOH), which has very similar properties to lime. The formation of the sodium hydroxide as part of the reaction also assists in maintaining the sodium cyanide in a soluble form.

Once the gold particles have been dissolved and have formed gold cyanide, there are two main methods by which the gold is then recovered, namely CIL, or Merrill Crowe.

CIL is the most widespread cyanidation process, both in Australia and throughout the world. As the name suggests, there is a leaching or dissolving process using cyanide and as part of that leaching process, activated carbon is included in the process, and is mixed with the ore and water (slurry) where it adsorbs (attracts) the gold onto its surface.

Gold particles leach (dissolve) very slowly, which is why there need to be multiple and very large leach tanks and why many alternative reagents, which would often need even more and larger leach tanks, are not commercially viable.

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[1] Information sourced from HTTPS://WWW.CYANIDECODE.ORG/ABOUT-CYANIDE-CODE/FAQ

In dilute cyanide solutions with normal oxygen levels (8ppm), gold dissolves at around 3 microns per hour, or put another way, a 1mm gold particle would take 300 hours to dissolve. Because of this very slow leaching rate, higher purity oxygen is often added to the leaching process to accelerate the leaching, and coarser gold particles are ideally removed separately using gravity recovery devices so that only finer gold particles of a size less than around 50 microns, or 1/20th mm are directed to the leaching circuit.

Once the gold particle is leached (soluble), then it is then recovered from that solution using activated carbon granules.

Activated carbon granules generally originate from coconut shell, although activated carbon can be produced artificially in the form of extruded carbon. The coconut shell is crushed and then activated via an accurately controlled heating (burning) process.

Coconut shell has very high porosity, which gives the activated carbon that is produced from the coconut an extremely high surface area. The soluble gold adsorbs to the surface of the activated carbon in what is termed a chemisorption process.

The chemisorption process is difficult to explain in simple terms. The best analogy is to compare the attraction or bond of the activated carbon surface and gold in solution, to a type of chemical magnet.

At lower temperatures, the gold solution is attracted to the surface of the activated carbon granule and then at higher temperatures, other forces (Van der Waals) repel the gold cyanide solution from the activated carbon surface.

This means that the larger activated carbon granules (2-4mm) can be mixed with the ore and water (slurry less than 0.5mm) in the leach tanks where the gold is dissolved. The larger activated carbon particles are then held in each leach tank by a screening configuration where they are able to adsorb or attract the gold cyanide onto their extensive surface area. These granules are then removed from the slurry and processed using solutions at higher temperatures to release or repel the gold cyanide off the activated carbon surface back into solution, but now at a much higher concentration. The gold cyanide in this higher concentration solution is then electroplated onto steel wool and then smelted and poured into a gold dore bar.

Merrill Crowe is rarely applied as a recovery method in modern day projects as it firstly requires a much higher cyanide concentration in the leaching (dissolving) and recovery process, and secondly because there is a need to separate (or filter) the solution from the solid so that the next part of the process can work, where the addition of fine zinc powder causes the gold to precipitate as a solid.

Cyanide can be manufactured, stored, transported, utilised and disposed of in a safe manner. It occurs naturally, with over 3,000 species of plants[2] known to synthesize cyanogenic compounds (i.e. cassava, lima beans and almonds). It is not toxic in all forms or concentrations and does not persist/accumulate in the environment.

Cyanide has an ‘emotive’ reputation, most likely the result of fiction novels and movies portraying it to be a murder weapon.

Cyanide does require, like most chemicals, thorough procedures to be adhered to for its transport, storage and usage, however, if handled correctly, as has been the case in Australia now for over 40 years, then it is a safe chemical to use.

One of the beneficial qualities of cyanide is that it readily attenuates or decomposes via a number of processes. The two most common are:

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[2] Cyanide action in plants – from toxic to regulatory – Irena Siegien

- **Volatilisation**, which is where the dissolved cyanide is in a sense vaporised, with the different cyanide complexes (or salts) reacting with water when the pH is below 9.0; and,
- **Biodegradation**, where the carbon (C) and nitrogen (N) that form cyanide (CN) are converted via the interaction of microorganisms to carbonate (CO_3^{2-}) and ammonia (NH_3), products similar to the fertilisers often added for agriculture.

3. ALTERNATIVE LIXIVIANTS OR CHEMICALS

A number of current alternative lixiviants, or chemicals that have been utilised on a small scale to extract gold are listed below:

- mercury
- chlorine
- thiosulphate
- glycine

3.1. MERCURY

Mercury can be utilised to recover free gold, typically associated with what are known as alluvial deposits. Alluvial deposits are generally located near to surface and the gold particles are coarse in size. This process is typically limited to laboratories or itinerant miners, as shown in Figure 2.

Figure 2 - Gold Recovery Using Mercury by Illegal Gold Miners[3]

Mercury is not considered to be a commercially viable option due to safety and environmental issues associated with mercury and its use.

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[3] Image sourced from Amazon Aid Foundation Website: https://amazonaid.org/treatment-needed-mercury-poisoning/

3.2. CHLORINE

Chlorination was utilised commercially in the 1800's. The gold is dissolved in a chloride solution at a pH of 3, which is very acidic. The use of chlorination commercially ceased in the late 1800's and replaced with cyanidation.

An atmospheric leaching process at pH 7 was developed in the 1980's to process gold ores containing higher copper levels, but the high reagent consumptions prevented it from being commercially viable.

A chlorination vat leaching process has been developed by Dundee Substantiable Technologies called the CLEVR Process™. The CLEVR process utilises sodium hypochlorite ($NaClO$) with sodium hypobromite ($NaBrO$) as a catalyst (to assist the reaction), under acidic conditions to leach the gold from sulphide ores.

The gold bearing solution is then recovered from the leached slurry via a solid/liquid separation (or filtration) stage before the gold is recovered on silica. The gold laden silica is then recovered from the solution and then smelted to produce a gold bar. An example of the proposed flow sheet is detailed in Figure 3.

A small scale 15 tonnes per day demonstration plant has been developed in Canada, but the process is not commercially available at this point. The complexity of the process is less viable for whole of ore processing, instead being more suitable for the processing of smaller scale flotation concentrates, where the gold grade has been upgraded and the overall mass of ore requiring treatment has been reduced.

Figure 3 - CLEVR Process™ Gold Extraction Process[4]

The chlorination processing option is not suitable for the McPhillamys ore due to the following:

- Safety and environmental issues associated with using chlorine;
- The ore cannot be concentrated to produce a high grade, low mass concentrate to minimise the size of the process;
- A commercial option for a low-grade whole of ore chlorination leach has not been commercially proven at the McPhillamys throughput rate.

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[4] Image sourced from Dundee Technologies web site: HTTP://DUNDEETECHNOLOGIES.COM/CLEVR-PROCESS

3.3. THIOSULPHATE

Thiosulphate has recently been utilised on a small scale for gold recovery in previously processed tailings in Western Australia. The small scale vat leach pilot plant was developed and operated by CSIRO in Western Australia.

Sodium thiosulphate readily dissolves gold and like other chemicals that are capable of dissolving gold, requires the use of an oxidant. In this case, copper or iron along with an oxidant stabiliser such as ammonia is utilised to achieve an acceptable rate of gold dissolution, while at the same time aiming to minimise the rate of thiosulphate oxidation (or loss). The chemistry is highly complex, and variations may result in the passivation of gold particles and lower gold recovery. Passivation is where the surface of the gold particle is altered and may then not dissolve.

Once the gold is dissolved, ion exchange resins are utilised to recover the leached gold. Ion exchange resins are synthetic materials often in the form of microbeads that consist of an inert matrix and are prepared using a solvent diluent to produce a porous structure, similar to coconut shell, which is the source of activated carbon in CIL processing.

Typically, resins are not as mechanically strong as activated carbon (currently utilised with cyanide leaching) and therefore the consumption rates are quite high. In most cases a solid/liquid separation stage is required so the resins are not in contact with a slurry. Resins are also expensive, when compared to activated carbon, have a smaller particle size requiring more specialised screening and a more complex elution process to recover the gold of the resin.

CSIRO are in the process of developing a small mobile facility, the aim of which is to process small scale, high-grade gold deposits. Currently their system has been trialled at Eco Minerals, Menzies, which is approximately 75km north east of Perth in Western Australia.

The process involved vat leaching of tailings, which had been previously processed in the early part of the last century. Vat leaching is a process where tailings or material is placed in a container of some sort and then solution containing the chemical that can dissolve the gold is added until the tailings or material is flooded. The solution is then circulated until the gold is dissolved.

The key findings from the CSIRO trial were:

- The consumption rate of the thiosulfate is typically proportional to the gold leach rate.
- The CSIRO process as shown in Figure 4, is based on treating small scale, high-grade deposits where good gold liberation can be achieved at a coarse grind size. The coarse grind size is necessary as the solution dissolving the gold must be able to infiltrate the material vertically, providing relatively high percolation rates if the vat leaching successful is to be successful;
- The process requires a solid separation (filtration) stage before adsorption of the leached soluble gold onto the ion exchange resins can occur.

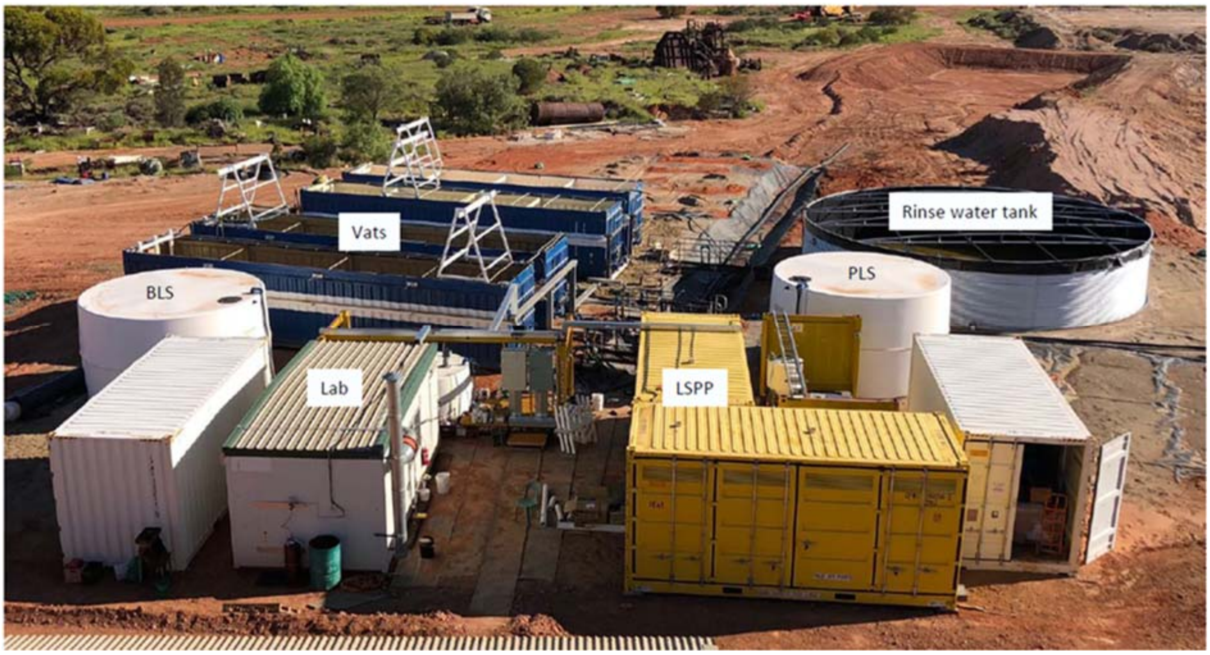

Figure 4 - CSIRO Thiosulphate Test Plant

CSIRO indicated that they have plans for an agitated leach circuit, which would then allow the process to be upscaled, but as yet, nothing has been constructed or commercially tested.

In addition to the CSIRO pilot plant at Menzies, Western Australia, the Barrick Goldstrike operation in Nevada USA, utilises calcium thiosulphate to leach gold after the ore has been processed via a pressure oxidation circuit.

A pressure oxidation circuit is normally used to oxidise sulphide minerals that are associated with the gold and which prevent the gold from dissolving. The pressure oxidation process is generally carried out in an autoclave at a temperature in excess of 200°C and at elevated pressures.

The oxidised ore is then leached in thiosulphate and the soluble gold is recovered onto an ion exchange resin. The resin then subjected to a two stage elution (or removal) process, the first removing soluble copper and the second removing soluble gold. The gold solution from the elution (or removal) stage is then electrowon (or plated) onto steel wool before being smelted to produce a gold dore bar.

The technical reaction for the leaching of gold with thiosulphate is as follows

$$4Au(s) + 8S_2O_3^{2-}(aq) + O_2(g) + 2H_2O \rightarrow 4Au(S_2O_3)_2^{3-}(aq) + 4OH^-(aq)$$

In the reaction shown, Au stands for gold and $S_2O_3^{2-}$ stands for thiosulphate. More familiar to most people are the O_2, which stands for oxygen and H_2O, which stands for water.

When the four are combined in the correct ratio, then gold thiosulphate ($Au(S_2O_3)_2^{3-}$) is formed along with hydroxide (OH^-), which has very similar properties to lime.

The Goldstrike operation processes a high-grade gold ore by industry standards that is amenable (or favourable) to the use of thiosulphate as a gold lixiviant (chemical) due to high concentrations of preg-robbing carbonaceous material and significant concentrations of arsenic (As) associated with the ore.

Preg-robbing carbonaceous material is generally a substance similar to peat and is problematic because it competes with the activated carbon in a normal CIL process thereby causing a reduction in gold recovery.

The thiosulphate processing option is not suitable for the processing of the McPhillamys ore due to the following:

- The ore cannot be concentrated to produce a high grade, low mass flotation product.
- A commercial option for a low-grade whole of ore thiosulphate leach has not yet been commercially proven at throughput rates equivalent to McPhillamys, without any pre-treatments, such as pressure oxidation.
- There is no major preg-robbing carbonaceous material associated with the McPhillamys ore.

3.4. GLYCINE

The GlyCat™ process has been developed to process gold ores than contain high concentrations of cyanide soluble copper.

Copper can be found in many mineral forms that are often categorised as either primary or secondary copper minerals. Primary copper minerals, such as chalcopyrite tend to have a copper component that is not readily soluble in cyanide. Secondary copper minerals however, generally have a copper component that is more readily soluble in cyanide and as a result, the cyanide consumption, or usage, for these minerals can be prohibitively high. Copper of this nature that dissolves readily in cyanide in these secondary copper minerals is known as cyanide soluble copper.

The Glycine process utilises a small amount of a glycine dominant lixiviant (reagent), in conjunction with cyanide to leach the gold bearing ore. The cyanide soluble copper preferentially bonds to glycine instead of cyanide freeing the cyanide to leach the gold.

The reaction of the copper with the glycine forms cupric glycinate which is an effective oxidant for the leaching of the gold, that is, it replaces the need for oxygen addition. Publications reference a decrease in overall cyanide consumption from 8 kg/t to 1 kg/t. Typical consumption rates for cyanide in whole of ore CIL processing circuits are less than 1 kg/t.

The glycine process option is not amenable to the McPhillamys ore as the cyanide soluble copper levels are not high enough to justify the process.

4. FLOTATION

4.1. OVERVIEW

An alternative processing flowsheet that does not use cyanide, but is dependent on the mineralogy of the ore, is the process known as flotation.

In simple terms, flotation relies upon the presence of minerals that have surfaces that can be made to be hydrophobic (repels water) through the addition of specific reagents or chemicals. Where a mineral surface can be modified to be hydrophobic, an air bubble can attach to the surface and if the air bubble is large enough and the mineral particle small enough, then the mineral particle will float to the surface.

All other mineral particles that do not have these properties sink and are discarded to the tailings stream.

The most common mineral particles that have surfaces that can be made to be hydrophobic are sulphide particles, so if the sulphide particles are associated with the gold, then floating them into a concentrate form, can make the recovery of the mineral and the gold economic.

The sulphide particles may be associated with a number of metals, for example, copper, nickel, lead, zinc, iron, etc. For gold recovery via flotation, the most common sulphides that tend to be associated with the gold are copper and / or iron.

The sulphide concentrate once collected normally needs to be filtered and then transported from the mine site by pipeline, trucks and /or rail to a port and then sold directly to a smelter (normally overseas).

An example of this is the Cadia Mine (Cadia) process plant in New South Wales, where the mineralogy of the ore has the vast majority of gold associated with copper sulphide (chalcopyrite), which can have its surface modified by chemicals to allow air bubbles to attach and then float to the surface where it is collected as a concentrate.

Another example of an operation that utilises flotation to produce a sulphide concentrate is the Evolution Mining Mount Carlton (Mt Carlton) operation in Queensland. Mt Carlton produces a sulphide concentrate using flotation, with the following design final concentrate specification:

These mineral sulphide particles associated with the gold that form the concentrate generally represent only a small percentage of the feed material that is processed, for example, from 1% to maybe 10% at a maximum. That is, the amount of concentrate that needs to be transported for further processing is a small percentage of the original amount of ore that is processed.

The mineralogy of the Cadia and Mt Carlton deposits, although significantly differently in the type of sulphides they each contain, have the common attribute that the gold is predominantly associated with sulphide minerals in the respective ores.

In Cadia's case, the gold is generally associated with chalcopyrite ($CuFeS_2$), a sulphide which can be recovered using flotation into a sulphide concentrate. In Mt Carltons case, the gold is generally associated with, pyrite (FeS_2), enargite ($Cu_3(As,Sb)S_4$) and tennantite ($(Cu,Fe,Zn)_{12}(As,Sb)_4S_{13}$), refractory sulphides that can also be recovered using flotation into a sulphide concentrate.

If in Cadia's case the ore was processed using direct cyanidation, then the levels of copper in the ore would lead to excessively high cyanide consumption and / or difficulty in preferentially adsorbing of the gold species onto the activated carbon granules in the leach tanks.

In Mt Carlton's case, if the ore was processed using cyanidation, then the refractory nature of the gold would mean that the cyanide would not directly dissolve the gold without other prohibitively expensive pre-treatment options.

4.2. MCPHILLAMYS FLOTATION TESTWORK

The discovery and development of any potentially valuable metal deposit, whether it be gold or any other metal, is always accompanied by a myriad of testwork programs to understand the different disciplines that will ultimately impact on the project should it be developed.

These may include but are not limited to the geological, mineralogical, geochemical, geotechnical, metallurgical characteristics of the deposit.

Such was the case for McPhillamys. Even though the geological and mineralogical characteristics of the deposit indicated that CIL was likely to be the most suitable processing option, a series of tests were carried out by both Newmont in 2010 and Regis in the following years to confirm whether an acceptable gold recovery could be achieved using flotation as a processing option.

In all cases, acceptable levels of gold recovery could not be achieved at commercially viable percentage mass pull or concentrate gold grade. In simple terms, what this means is that the gold is not concentrated or associated with mineral sulphides to a level where a small amount of concentrate could be recovered with a high percentage of the gold.

This is because a higher percentage of the gold at McPhillamys is not directly associated with sulphide minerals, rather it is what is termed as free milling, meaning that the surfaces of these gold particles are not able to be made hydrophobic through the addition of chemicals, and hence they can not be floated using air bubbles into a concentrate form.

Ore samples from throughout the McPhillamys deposit were subjected to flotation testwork. Five McPhillamys composite ore samples, as shown in Figure 5, each representing a two-yearly mining period were subjected to laboratory flotation tests.

The (rougher) flotation testwork mass and assay results are detailed in Table 1, while the gold grade/recovery curves are detailed in Figure 6 and the copper grade/recovery curves in Figure 7.

The results indicate that the neither the gold grade (4.07 – 6.38 g/t Au) or the copper grade (0.27 – 0.46% Cu) of the sulphide concentrate are high enough to produce a saleable concentrate (sulphide or copper) for any of the five McPhillamys composite samples.

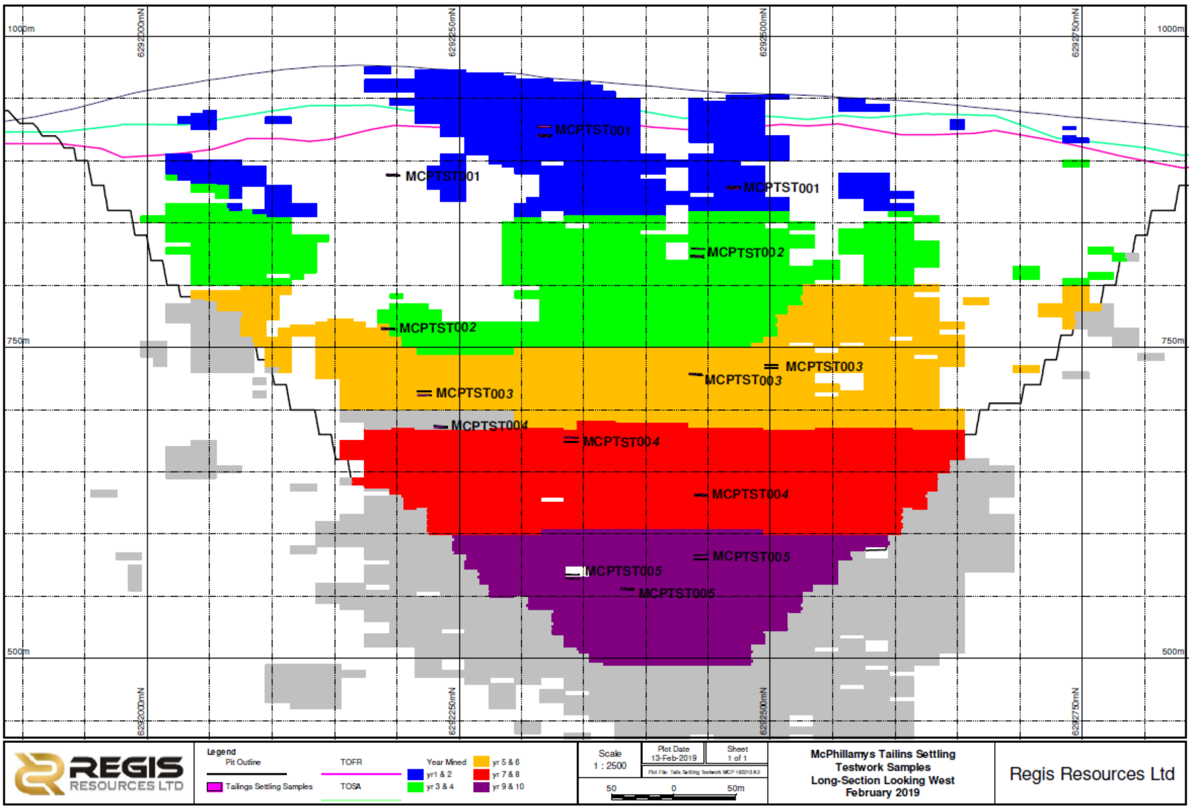

Figure 5 - McPhillamys Gold Project Two Yearly Composite Samples

Table 1 - McPhillamys Flotation Rougher Testwork with Cadia & Mt Carlton Results

Sample	Mining Period	Mass Cum %	Au g/t	Au dist %	Cu g/t	Cu dist %
MCPTST001	1-2	20.65	5.67	92.77	3,164	93.74
MCPTST002	3-4	17.48	4.07	96.63	3,877	94.59
MCPTST003	5-6	20.48	4.88	95.81	2,658	94.61
MCPTST004	7-8	19.77	6.38	96.03	3,872	96.17
MCPTST005	9-10	19.32	4.37	98.13	4,610	95.83
Average		**19.54**	**5.07**	**95.87**	**3,636**	**94.99**
Cadia	Rougher	3.10	17.00	72.00	45,000	93.00
Cadia	Final	0.70	68.00	69.00	220,000	90.00
Mt Carlton	Rougher	9.60	33.10	93.30	44,000	93.30
Mt Carlton	Final-	6.80	45.90	91.60	63,000	95.30

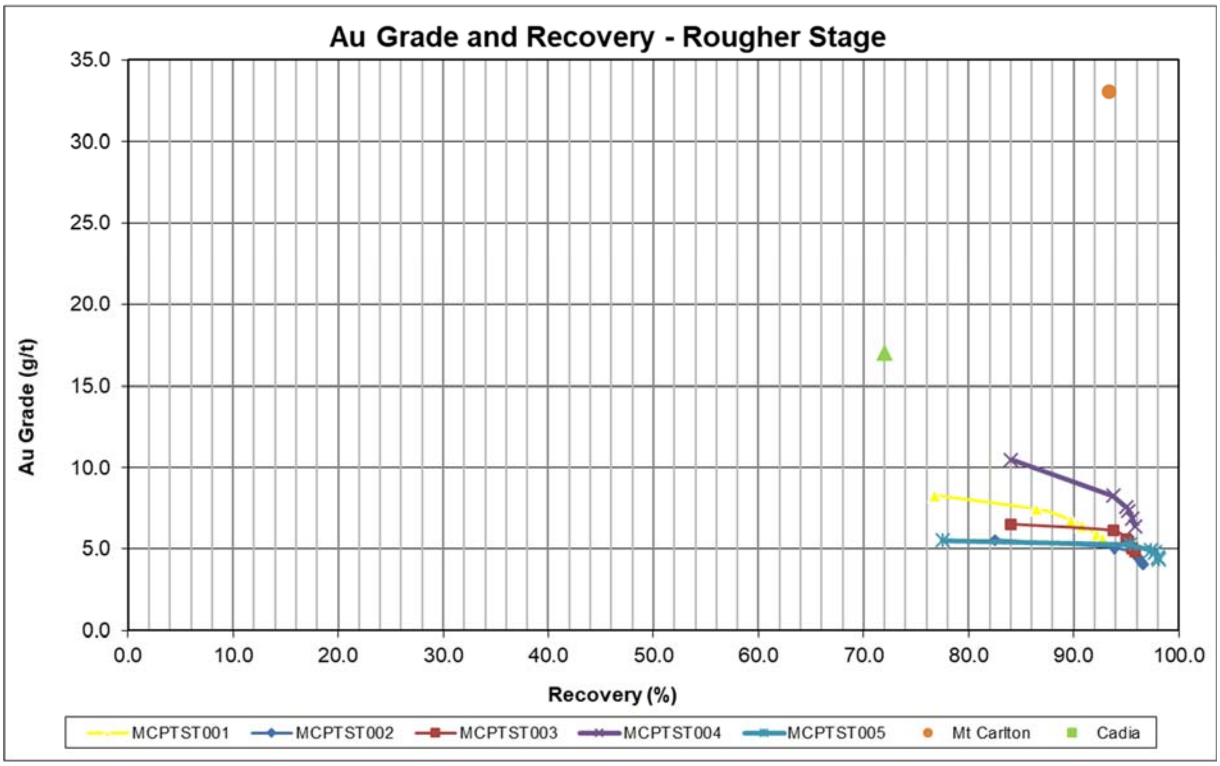

Figure 6 - McPhillamys Gold Rougher Grade/Recovery Curve

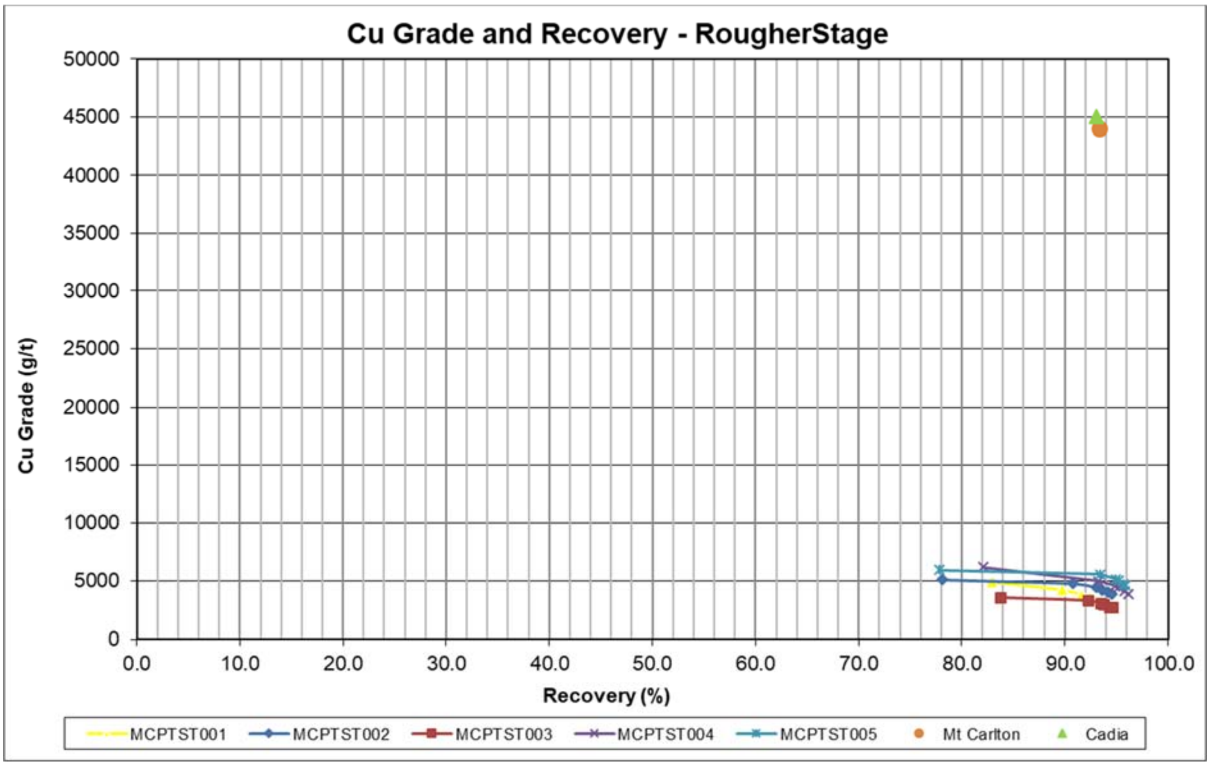

Figure 7 - McPhillamys Copper Rougher Grade/Recovery Curve

Figure 8 compares the McPhillamys rougher flotation testwork mass pulls with those of Cadia and Mt Carlton.

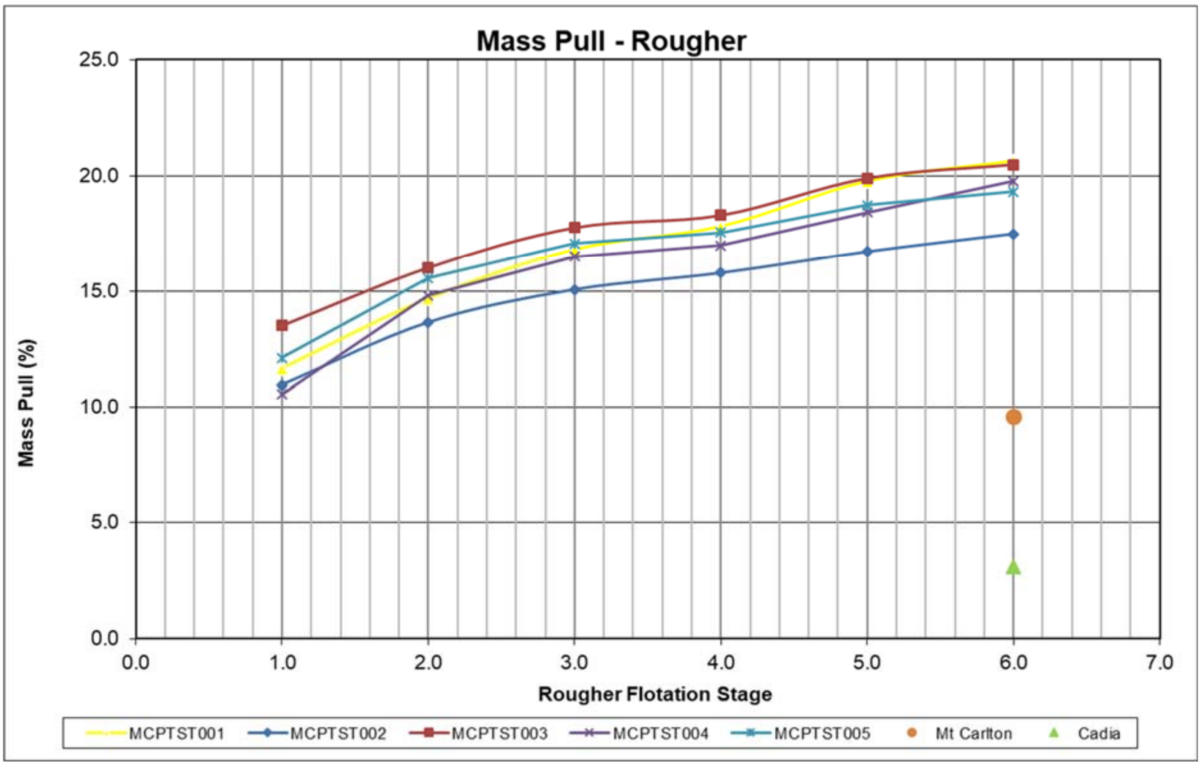

Figure 8 - Rougher Flotation Stage Mass Pull

5. SUMMARY

Table 2 below shows a high-level review of the impact of different key variables on the selection of the desired gold recovery method for the McPhillamys Gold Project. A colour coding system has been employed to define the impact of each variable. Green indicates the best result, black moderate and red the worst result.

Table 2 - McPhillamys Gold Recovery Methodology Analysis

Variables	Cyanide Leaching	Alternative Lixiviant	Flotation
System Complexity	**Simple**	**Complex**	Average
Reagent – Safety	**Safe**	Moderate	**Safe**
Suitable for large scale	**Yes**	No	**Yes**
Gold Recovery	**Good**	Average	**Poor**
Final Product	**Gold Bar**	**Gold Bar**	**Bulk Concentrate**
Capital Cost	**Low**	**High**	Medium
Operating Cost	**Low**	**High**	Medium

Cyanide leaching was selected as the optimal gold recovery method for the McPhillamys Gold Project because:

- It is a proven technology, especially for large scale / low grade gold deposits and is utilised to process gold bearing ores worldwide and at several gold mines within NSW;
- Flotation testwork did not provide acceptable gold recoveries, or a saleable gold concentrate grade. The (rougher) concentrate produced during laboratory testwork did not;
  - Contain enough gold (>40 g/t Au) to enable the production of a commercially viable sulphide concentrate;
  - Contain enough copper (>14% Cu) to enable to the production of a commercially viable copper concentrate;

  - Reject enough mass (<10%) to make the process and concentrate production options commercially viable. Cadia’s final concentrate mass is 0.7% while Mt Carltons final concentrate mass is 6.8%; and
- Alternative lixiviants such as thiosulphate, although potentially viable in the coming decades, have not been successfully implemented on large scale, low grade gold deposits where the entire ore stream requires leaching.