TECHNICAL MEMORANDUM

TO:	Paul Williams
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FROM:	Rob Coleman
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SUBJECT:	Applicability of AmmLeach® Technology to Koongie Park Project

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INTRODUCTION

Copper sulphide deposits are typically processed using froth flotation to produce a mineral concentrate that can be further refined to copper metal through smelting. With appropriate changes in reagent chemistry the flotation process can also be applied to copper oxide deposits to produce a high-grade concentrate, from which the copper can be chemically leached and refined. For lower grade oxide deposits, however, it is often more economically viable to bypass the energy intensive particle size reduction processes required for flotation and leach the whole ore by irrigating a series of heaps formed from very coarse particles. Acid solutions have been widely used for this application but are problematic when dealing with ores that contain a high percentage of carbonate gangue minerals. This creates a niche application for leaching systems based on alkaline solutions, such as ammonia.

Since ammonia-based technology has not yet achieved widespread commercial application, Core Resources has been approached by AuKing Mining Limited to provide a report into the viability of applying the patented ammonia based AmmLeach® process to the ore deposits associated with their Koongie Park Project. This report considers previous AmmLeach® testwork undertaken at other projects around the world and compares the mineralogy and host rock geology to that of the Koongie Park deposit.

PREVIOUS APPLICATIONS OF AMMLEACH® TECHNOLOGY

Early applications of ammonia to the recovery of copper, such as the Arbiter process developed by Anaconda and the ammonia leaching of flotation concentrate at Escondida, had very little commercial success. The AmmLeach® process originally developed by Alexander Mining was therefore based around the concept of adapting the process to the specific mineralogy of a deposit to maximise the likelihood of success. In the case of the Leon mine in Argentina, this meant optimising the system to leach copper oxides as carbonate, whereas previous ammonia systems targeted chalcocite via an oxidative ammonia/ammonium sulphate leach. Part of this optimisation involved using a hypochlorite cure to assist in the subsequent solubilisation of secondary Cu minerals in the oxide zone. Further modifications were made to target soluble Zn carbonates.

The choice of an ammonia leach system in the case of Leon was based on very high acid consumptions of 300 to 1000 kg/t when using a conventional sulphuric acid leach. Froth flotation testing also failed to achieve an economic recovery or grade. In contrast, a 60 g/L ammonia sulphate leach was able to extract more than 80% of the contained copper within 72 hours under laboratory conditions. The extent of Cu dissolution in this case was proportional to the free ammonia concentration, making bulk solution kinetics more important than the overall residence time. Changing to an ammonia/ammonium carbonate leach system achieved similar results; however, this change proved beneficial in terms of reducing the overall ammonia consumption. Attempts were made to simultaneously recover the silver associated with this orebody using sodium thiosulphate, but this proved unsuccessful due to degradation of the thiosulphate by excess copper as tetra amine. Although there was some evidence to suggest that silver may be recoverable in a subsequent leach stage, this idea was never fully developed prior to cancellation of the mine project.

Another copper deposit that is poorly suited to conventional acid leaching due to a high concentration of carbonate gangue is the Lady Annie deposit in Queensland, Australia. Adaptation of the AmmLeach® process to this ore deposit included curing with ammonium carbonate prior to an ammonia/ammonium carbonate leach, which laboratory-scale testing indicated would provide a slightly lower copper recovery (63%) than using an uneconomically sustainable 200 g/L solution of sulphuric acid in an acid leach (68%). However, unlike the Leon deposit, leaching of the Lady Annie ore was found to be limited by residence time rather than free ammonia concentration.

Downstream processing with AmmLeach® is very similar to that used in a conventional solvent extraction (SX) plant, which is well established technology that poses a very low technical risk. The only changes required in the case of AmmLeach® are minor and focused solely on minimising ammonia loss. Previous ammoniacal leach systems have utilised LIX84I as a lixiviant to remove both copper and nickel from solution, and this same extractant has also been demonstrated at Leon to achieve comparable recoveries from an ammonium carbonate heap leach conducted without curing over a residence time of 120 days. However, the presence of reducing species prompted the addition of an oxidative curing step in subsequent trials. With either leach system, an equilibrium loading of the lixiviant was found to be achieved faster when the ore was finely ground,

Column leach tests conducted at Leon identified that the maximum copper recoveries achieved in small-scale laboratory testing were not practical to achieve on a larger scale due to a dramatic increase in ammonia consumption. Nevertheless, a copper extraction of 90% was achieved with 3-5 kg of ammonia per tonne of ore during these initial tests. A subsequent pilot plant campaign, however, was only able to achieve a maximum copper extraction of 45.8% from a limestone/sandstone hosted copper ore. This was attributed to the presence of elevated levels of copper in the coarsest size fractions of the feed, but it was not determined whether this was because of unliberated copper minerals present in the coarser size fraction or simply that the leaching kinetics are increased by an increase in the ratio of surface area to volume of the ore particles. Nevertheless, this prompted a change from run of mine (ROM) ore as the feed to material that had been crushed to -38 mm, which increased copper recovery to between 70.6 and 76.3%. It is worth noting though that the decrease in particle size was facilitated by the weak physical strength (Bond Work Index) of the ore and a high permeability to fluids due to a low concentration of clay minerals. A finer feed was also considered to pose less risk of damaging the impermeable plastic membrane placed under the heap to contain the leach solution.

A second pilot campaign at Leon using a limestone hosted ore crushed to 100% passing 102 mm achieved a copper extraction of 77%. It was noted that this leach process can lead to the precipitation of calcium, but no indication was given as to whether this could cause any long-term issues on a continuously operating plant.

No metallurgical testing has yet been conducted to confirm the viability of applying the AmmLeach process to ore samples from Koongie Park.

COMPARISON OF GEOLOGY

The host rocks of the Leon deposit in Argentina are strongly brecciated and altered, which is to be expected from a Mississippi-Valley Type (MVT) hydrothermal deposit that is hosted in limestone. The original source of the mineralising fluid for this deposit is not definitively known, but given the type of deposit, is likely to have been relatively low temperature (100-150°C). Thus, although it is possible that this fluid may have contained sufficient sulphur to produce the sulphides present in the primary ore zone, they could also have been produced through the reduction of sulphate by organic matter. In either event, mineralisation occurred as a result of hydrothermal fluid passing through existing rock, producing a characteristic structure and making the material very weak and easily fractured. Moreover, as the original rock is not heavily altered, there is a low concentration of clay minerals that can cause issues with grinding and/or reduce the permeability of a heap leach. The downside to this type of mineralisation is the presence of hydrocarbons in the original sedimentary rock, which can consume ammonia during leaching or interfere with the lixiviant during solvent extraction. However, curing with sodium hypochlorite was found to be effective in passivating these organic species.

The Lady Annie deposit is part of the Mount Isa inlier and is hosted by a sedimentary sequence of siltstone, sandstone, dolomitic sandstone and some minor quartzite. Unlike Leon this is not a MVT deposit, but rather a stratiform-type hydrothermal type of mineralisation. The key distinction is that the mineralising fluid at Lady Annie most likely moved upward along a fault from a much deeper sedimentary basin into shales, where it then reacted with relatively recent organic matter to produce a chalcocite-rich primary deposit. This primary deposit has subsequently weathered and oxidised to depths ranging from 20 to 90 m from the surface.

The Koongie Park deposit is different from both Leon and Lady Annie in being a volcanogenic massive sulphide (VMS). The key difference here is that the primary ore deposit is not formed within older host rock, but is instead formed at around the same time as the host volcanic and sedimentary strata to produce characteristic bedding in parallel lenses. However, unlike other many other VMS deposits, the Koongie Park deposit has formed in close association with carbonate rock. Primary mineralisation is still the result of hydrothermal fluid, but at a much higher temperature (up to 400°C) than in a MVT or stratiform-type deposit. The hydrothermal nature of the mineralisation could see it respond to the AmmLeach® process in a similar way as the other two deposits.

COMPARISON OF MINERALOGY

The primary ore zone of the Leon deposit is dominated by chalcocite and bornite, which are gradually replaced closer to the surface by chalcopyrite and tennantite, followed by galena and sphalerite. Oxide mineralisation occurs to a depth of up to 90 m and is characterised by the presence of secondary minerals such as malachite, azurite, digenite and covellite. The overall copper grade is relatively low at 1.2% copper, with only 75% of this copper present in mineral species that are soluble in sulphuric acid. There is very little iron associated with this deposit, either as an oxide or sulphide, but a very high carbonate content of 50-55% is problematic to acid leaching.

The oxide zone of the Lady Annie deposit has an even lower copper content than Leon of 0.8%, though this increases slightly to 1.0% in the transition zone between the oxide and primary sulphide mineralisation. Unlike the Leon deposit, however, Lady Annie has very high levels of iron as oxide (14%) that can dissolve in a conventional acid leach and contaminate the downstream electrowinning of copper. Relatively high levels of magnesium (4.8%) and calcium (8.5%) can cause similar problems. This ore also has very low concentrations of metals likely to be soluble in an alkaline leach system, such as cobalt (<0.02%), nickel (0.0%) and zinc (0.0%). The absence of these metals simplifies the application of an alkaline leach system, yet also reduces the potential value that can be extracted from the ore. Mineralisation in the oxide zone is largely controlled by the structure of the original host rock and tends to be dominated by relatively coarse (300-400 µm) polycrystalline masses of malachite and psuedomalachite. Some intergrowth of these two minerals with haematite and goethite also occurs, and comparatively fine (70 µm) particles of psueodomalachite have been found to be interlocked with quartz.

In the transition zone of the Lady Annie deposit mineralisation is dominated by sulphides, but with accessory malachite, cuprite and native copper. Covellite is also known to be present as fine particles in malachite or to form composite particles with goethite and haematite in carbonates, particularly siderite and iron-rich dolomite. Relatively coarse (500-700 µm) particles of covellite have also been identified in quartz and dolomite. In rare instances chalcopyrite can occur in dolomite, but usually as a residual core in particles that have been almost fully weathered to chalcocite. Minor quantities of azurite, chrysocolla, cuprite and native copper are also found in the original sediments as a result of oxidation.

The Onedin deposit of Koongie Park has a copper grade of 1.8%, which is primarily contained within malachite. As with the Lady Annie deposit, there is a high percentage of iron oxide present in the oxide and transition zone that could prove problematic in the electrowinning stage of a conventional acid leach and solvent extraction process. Zinc carbonate (smithsonite) and magnesium carbonate (magnesite) minerals are present in the Onedin oxide zone at concentrations of less than 5%, but increase to as much as 20% in the transition zone. In the primary ore zone the mineralisation is dominated by the presence of dolomite with a lesser amount of calcite, whereas the transition zone is dominated by quartz. The transition zone also contains calcite, as well as iron-rich dolomite with intergrowths of talc. To date there has been no detailed calcium or carbonate analysis of this deposit, with previous testwork relying on samples taken from a single intercept of the orebody from a single drillhole. A more thorough understanding of the distribution of carbonate across the orebody itself, however, is crucial to accurately defining the sulphide/oxide interface. In other words, a clear distinction needs to be established between ore amenable to conventional sulphide flotation and that requiring more complex processing methods such as AmmLeach® in order to assess the importance of the AmmLeach process to the overall viability of the project. More work is also needed to better understand the distribution of carbonates within the ore to validate the benefits of an alkaline leach over a more conventional acid leach system.

Table 1 - Mineralogy of Koongie Park Onedin Deposit (Pontifex Report, 2007)

	Sphalerite	Galena	Pyrrhotite	Pyrite	Chalcocite	Goethite/Limonite	Malachite	Fe-Dolomite	Smithsonite	Cerrusite	Hemimorphite	Chlorite	Talc	Quartz	Haematite
Oxide (Vol%)	Trace	-	-	Trace	Trace	~50	~3	-	-	-	Trace	~10	~10	~25	~5
Transition (Vol%)	1.1	0.8	0.2	1.5	0.3	27.5	-	~5	5	~3	4	6.3	16.6	17.3	Trace

OTHER FACTORS

Pilot-scale leaching and laboratory column tests on the Leon ore confirmed that it had a high permeability to leach solutions, even when crushed. Testing on the Lady Annie deposit, however, does not appear to have proceeded past bench-scale tests in which the permeability of the ore was not assessed. Similarly, there is no data available for the Koongie Park Project that confirms the ore is amenable to heap leaching, which represents a technical risk given the limited information available concerning the potential for precipitation of particular ions within the AmmLeach® system. However, it is noted that since the majority of copper in the oxide zone is present, the extent of crushing that may be required prior to leaching is another factor that has not yet been considered, yet could be significant if there is no preferential breakage between the target copper minerals and host rock; i.e., there is still a question as to how fine the ore needs to be in order to achieve a suitable level of copper extraction. These risks are typical for most heap leach operations at early stages of project development and mitigated through early stage testwork.

Another area of risk with the Koongie Park Project is the co-recovery of both copper and zinc using the AmmLeach® process. Although the solubility of zinc carbonates in ammoniacal solutions has been well established since the advent of the Schnabel process in 1880, there is a question as to whether simultaneous leaching of copper and zinc will prove more effective than the attempts to leach copper and silver at Leon. If both metals can be leached simultaneously, then the risk shifts to whether the copper can be continuously extracted without an unwanted build-up of zinc or other ammonia-soluble metals accumulating on the lixiviant. Such tests are a standard part of any solvent extraction test program but represent a second hurdle that must be cleared even if initial tests of the AmmLeach® process prove successful. Further to this is the question of whether the zinc can also be efficiently extracted using a separate lixiviant. Early stage testwork is recommended to address these risks.

CONCLUSIONS

With the AmmLeach® process having not yet progressed beyond pilot scale testing on an orebody, there is a risk that the process may not produce sufficient metal grades or recoveries to be economically viable. Such risks are an inherent part of any new mining project but need to be assessed in relation to their importance to the overall project. As indicated in the Project Prospectus, the success of the project is not tied to the success of the AmmLeach® process and this is just one of many options that are being explored. However, from a technical point of view there is certainly enough evidence to suggest that for the Koongie Park Project the use of AmmLeach® rather than a conventional acid leach may be advantageous in minimising the co-extraction of iron and allowing for the recovery of both copper and zinc from the same leach system. Furthermore, the extent of testing that would be required to establish the potential performance of the AmmLeach® process represents a small investment relative to the potential value of the project, with progression to larger pilot-scale testing only required if the decision is made to progress this process to the engineering design stage.