

In place leaching of oxidized gold deposits. A new method for recovering stranded gold resources?

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A modified *in situ* leaching method for extracting gold from oxidized gold ores using a non cyanide lixiviant is proposed. A non cyanide lixiviant is suggested because of the obvious concerns posed by injecting cyanide bearing solutions into the subsurface. Oxidized gold ores are the initial focus because earlier research on the use of sodium thiosulphate as a lixiviant under anaerobic conditions indicated that the presence of pyrite led to rapid thiosulphate breakdown. A reconnaissance research programme, involving ore characterization and hydrometallurgical testwork on samples from four Australian ore deposits and preliminary reactive transport modelling studies was carried out. This work showed that lixiviant-oxidant combinations of sodium thiosulphate and ferric EDTA, and iodide and iodine are both capable of extracting high percentages of accessible gold from the selected samples under anaerobic conditions. The ore characterization and reactive transport studies, suggested that both physical and chemical methods of permeability enhancement may be required to lift bulk permeability and the availability of gold for dissolution to sufficiently high levels to obtain adequate gold recoveries. Physical permeability enhancement could be achieved by blasting and/or hydraulic fracturing of the ore. Assuming that such methods prove to be both necessary and economically viable, the mining method would no longer be regarded as simple *in situ* leaching. Therefore, the term 'in place leaching' has been adopted for the proposed gold extraction system

Introduction

The concept of leaching metalliferous ore deposits *in situ* to recover valuable metals from injected solutions has attracted research interest over many decades. Despite this, the technique is only employed commercially in the uranium mining industry with approximately 20% of global uranium production being recovered via this method (OECD¹). A major attraction of such an approach is that it offers the possibility of recovering metals from mineral deposits economically without leaving any visible mark on the environment in the form of open pit excavations, tailings dams or surface waste dumps.

The 'stranded gold resources' referred to in the paper title are gold deposits which are presently not economic to mine with conventional open pit or underground mining methods owing to one or more factors. These include the deposits being: (1) too small; (2) too low grade; (3) too far from an existing mill; and (4) having too high an open pit stripping ratio. Many such deposits are known within Australia as a result of decades of successful mineral exploration.

Use of the term '*in situ* leaching' is usually taken to mean that the ore deposit itself has not been physically disturbed. In-place leaching is generally taken to mean leaching of broken ore in an open pit or underground stope. In this paper, we extend the concept of in place leaching to refer to leaching of material *in situ* in which permeability has been enhanced through low intensity blasting or hydraulic fracturing methods and/or through chemically induced dissolution of gangue material.

This paper describes preliminary results from a research programme aimed at evaluating the possibility that some oxidized gold deposits in Australia might be mined profitably by in place leaching using a non cyanide lixiviant. The latter is being considered to overcome possible concerns over the fate of the leach solution and its effects on the environment. A range of possible lixiviant-oxidant combinations has been identified, the two most important being sodium thiosulphate ferric EDTA and iodide iodine.

An extensive literature research into the applicability of non cyanide lixiviants for the extraction of gold from ores has been developed. Some authors have considered the potential for *in situ* gold extraction specifically using iodide (e.g. Fazlullin *et al.*², Kubo³). One, three year field test was carried out in an attempt to extract gold from telluride minerals at the Ajax Mine in Colorado from 1976 to 1979 but with poor results (Chamberlain and Pojar⁴).

A striking feature of the research programme described herein is its multidisciplinary nature. Therefore, the research involved integration of regolith studies, ore petrology, hydrometallurgical and hydrogeological testwork, hydraulic fracturing and detonics along with numerical simulations of the physical and chemical behaviours that would characterise the proposed gold extraction system.

Geology of target ore deposits

The immediate impetus for the research programme was the results of earlier work (Zhang *et al.*⁵; Heath *et al.*⁶; Zhang

and Jeffrey⁷) which indicated that a combination of sodium thiosulphate as lixiviant, ferric as oxidant and thiourea as a catalyst for gold oxidation might be usable for anaerobic leaching of gold ores. This work also indicated that the presence of pyrite results in rapid catalysed oxidation of the sodium thiosulphate rendered the method ineffective in the absence of a method for passivating the pyrite prior to lixiviant introduction and throughout the leaching process. Therefore, this research has focused on gold ore deposits in which pyrite is absent.

Primary ore deposit characteristics

The current focus of the research program is on a class of ore bodies known as orogenic gold deposits (Groves *et al.*⁸). This class of deposit includes gold orebodies formed in large deformation events. In Australia, the majority of such orebodies were formed during the late Archaean in Western Australia and Palaeozoic in Victoria/New South Wales.

Individual deposit descriptions vary widely, however, one common characteristic is that structural control is important. Faults, including fault bends, jogs and intersections, and rheology contrasts all play an important role in ore deposition. Therefore, high permeability at the ore depositional site at the time of ore formation seems to have been important. Such zones may also have enhanced permeability at the present day, as weathered fault zones may form fractured rock aquifers with significant bulk permeability (e.g. see Sara⁹).

Host rocks to the gold mineralization are also widely variable, however, mafic volcanics and intrusives and iron-rich sediments are more commonly mineralized than other lithologies.

Orogenic gold deposits generally contain minor sulphides, the most common of which is pyrite. The latter is commonly a host for gold. Furthermore, gold is typically found within or in selvages to quartz veins.

Weathering effects

Given the problem of catalyzed oxidation of thiosulphate on pyrite grains, the research focus is on the weathered portion of orogenic gold deposits where sulphides have been replaced by iron oxides or removed altogether. Therefore, a major area of investigation is the variation in regolith geology that may be relevant to the leaching of gold ores. Given that the ore deposits mentioned herein are located in the southern half of Western Australia and South Australia, the detailed understanding of the regolith on the Yilgarn Craton of Western Australia, developed over the last 30 years, is especially relevant (Anand and Paine¹⁰).

South-Western Australia was subjected to a prolonged period of tropical weathering during the Tertiary Era followed by arid weathering in more recent times. The tropical weathering resulted in the development of a lateritic weathering profile consisting of an upper lateritic duricrust, rich in hydrated iron oxides underlain by intensely weathered regolith layers, known as the upper saprolite and lower saprolite. These saprolite layers are underlain by more weakly weathered saprock. Mineralogy of the upper saprolite is dominated by kaolinite and quartz, the lower saprolite contains a greater variety of clays and some remnant primary minerals and the saprock is a transitional zone to the fresh rock below. The porosity of the upper saprolite is typically quite high, averaging 20 to 30%, however, permeability is quite low because the interconnected pore apertures are very small, typically from

<1 to 10 microns. Porosity tends to become progressively lower, deeper in the profile, however, permeabilities are generally higher especially within the saprock zone.

Gold distribution within the saprolite zone in the Yilgarn Province of Western Australia, takes two general forms depending on whether the mineralization is found north or south of the 'Menzies Line' (Butt *et al.*¹¹). The Menzies Line is a line oriented roughly east-west which passes through the township of Menzies in Western Australia, located at 121° 01'E and 29° 41'S, about 130 km north of Kalgoorlie. In the northern area, gold mineralization within the saprolite and saprock is generally found within a few metres of the weathered primary lode position. In the southern area, gold mineralization has been partly or wholly depleted from the upper saprolite (Butt and Zeegers¹²), probably during post Tertiary arid phase weathering.

Groundwater chemistry

Groundwater chemistry is an important consideration for *in situ* leaching. Gold species are only stable within specific pH ranges and salinity may also be a factor in leaching efficiency. In the Yilgarn Province of Western Australia, groundwater chemistry also appears to change around the Menzies Line. Therefore, Gray¹³ showed that: (1) north of the Menzies Line, groundwater tends to be near neutral in pH and relatively low in salinity away from the axes of valleys and (2) south of the Menzies Line, groundwater pH varies between 3 and 5 in upper saprolite, tending towards neutral with depth and with generally higher salinity, becoming hypersaline at depth and in the vicinity of salt lakes.

Research challenges

The research programme described in this paper is aimed at gaining a preliminary assessment of the major risks associated with this new, possible, mining method. Many of these risks result from variations in the deposit geology and groundwater chemistry, as described above. Given that the target orebodies can only be modified in limited ways relative to what is possible with more conventional mineral processing methods, the primary research challenge is to identify ore deposits with *in situ* characteristics which would allow recovery of a significant percentage of the gold held in the resource. In this context, we would consider 40% or more as a significant percentage.

Therefore, the research challenges under consideration in this paper are: (1) the effectiveness of the selected lixivants in leaching gold from typical Australian oxide gold ores (2) the likely permeability of typical oxide ore environments prior to the use of any methods for permeability improvement (3) the probability that the lixiviant will be able to make direct contact with a sufficiently large percentage of the gold to ensure adequate metal recovery in selected ore deposits (4) stability of the selected lixivants in the presence of the likely gangue minerals over a period of weeks or months (5) the predictability of lixiviant movement and recovery from the subsurface and (6) the potential of various methods to enhance ore permeability.

An additional potential issue that future research may need to consider is the potential impact of bacteria on the stability and performance of the candidate lixivants (especially thiosulphate).

Hydrometallurgical experiments

Leaching experiments were carried out in order to demonstrate the effectiveness of some non cyanide lixiviant

systems under anaerobic conditions. The oxide gold ore samples were collected from four sites in Australia; namely Tunkillia, Moolart Well, Glendower and Cornishman. The sizes and average gold grades are presented in Table I.

The location of the four deposits is provided in Figure 1. Brief details of each deposit are as follows:

- Tunkillia is located in the Gawler Craton of South Australia. The tested samples consisted of weathered, fractured augen gneiss
- Moolart Well is located in the Yilgarn Craton of Western Australia north of the Menzies Line. The tested samples consist of saprolite
- The Glendower and Cornishman deposits are both located in the Southern Cross mining district within the Yilgarn Craton of Western Australia south of the Menzies Line. The Glendower samples consisted mainly of weathered fractured banded iron formation. The Cornishman samples consisted of weathered fractured mafic volcanics.

The leaching was run in rolling bottles which were fully loaded with slurries containing 37% solids and sealed to minimise contact with oxygen. Several potential lixiviant solutions were investigated. Two systems was of particular interest. One was the thiosulphate thiourea ferric EDTA system, in which thiourea is a catalyst for gold oxidation and ferric EDTA is an effective oxidant (Zhang *et al.*⁵). The advantages of this system over the traditional thiosulphate ammonia copper system include: (1) sodium thiosulphate may be used if ammonium/ammonia is environmentally not acceptable; and (2) ferric EDTA is much less reactive than

Table I
Sizes and gold average grades of various oxide ores

Sample	Size	Au (g/t)
Tunkillia	97% -150 μ m	1.48
Moolart Well	<1 mm	3.71
Glendower	<1 mm	1.25
Cornishman	<0.5 mm	1.03

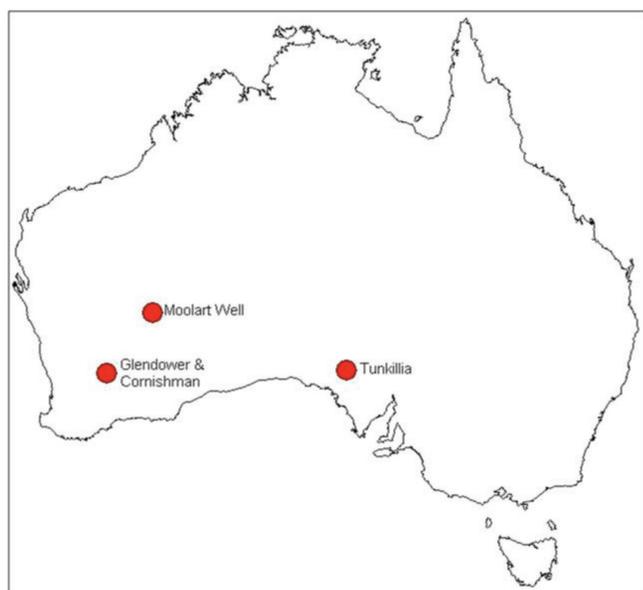


Figure 1. Location of the four gold ore deposits in Australia from which oxide gold ore samples were obtained

copper with thiosulphate and so is particularly suitable for anaerobic leaching. The second important system is the iodide iodine system in which gold is oxidized by iodine to AuI_2^- (Davis and Tran¹⁴; Angelidis *et al.*¹⁵).

Figure 2 shows the results from the thiosulphate leaching. As can be seen, except for Moolart Well, all the samples were leached effectively by thiosulphate with more than 90% of the gold recovered. The leaching was fast and most of the gold was leached within 24 hours. In the case of Moolart Well, it is believed that the lower gold recovery was due to an increase in the pH of the solution upon contact to the ore. Such a pH increase results in the ferric EDTA oxidant being less effective.

Similar results were obtained from the iodide iodine leaching which are presented in Figure 3. The leaching kinetics are even faster with most of the gold leached within 6 hours.

Given that the leaching conditions were not necessarily optimized, these results are considered to be very encouraging.

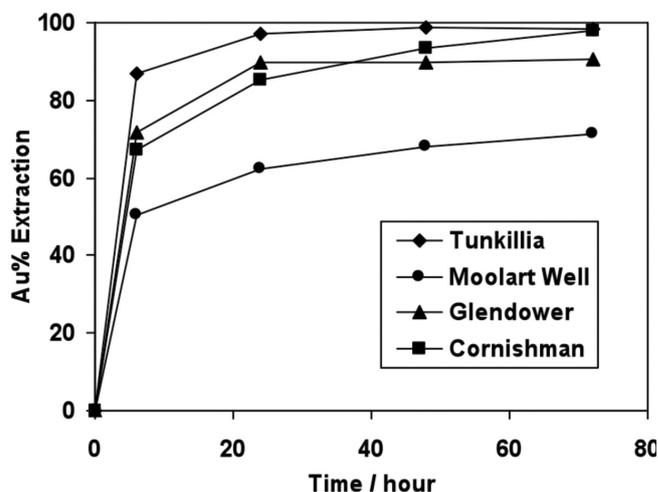


Figure 2. Gold extraction profiles during the leaching of various gold ores using a solution containing 0.1 M $Na_2S_2O_3$, 10 mM thiourea and 3 mM FeEDTA

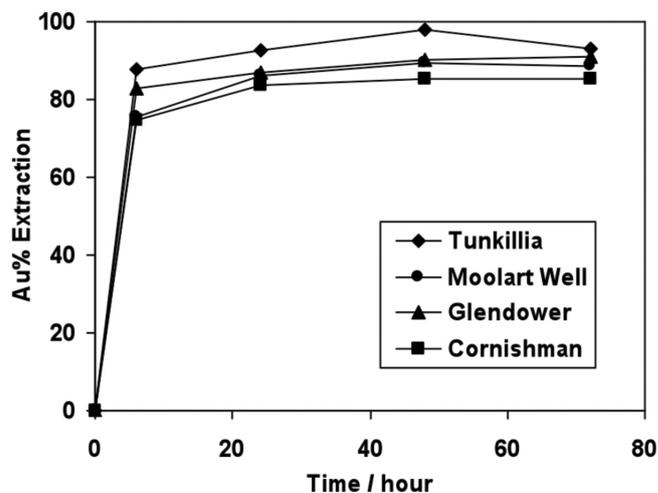


Figure 3. Gold extraction profiles during the leaching of various gold ores using a solution of 2 mM I_3^- and 16 mM I^- (except for Tunkillia where half of the concentrations were used)

An important consideration for the in place leaching method under consideration here is the stability of the candidate non cyanide lixiviants given likely transit times from weeks to months between the injection and extraction wells. Separate lixiviant stability tests in the presence of pure goethite, hematite, kaolinite and one ore sample are in progress. Initial results, after 8 weeks, indicate that polythionate formation in the presence of both the pure minerals and the ore sample is very limited (less than 2% after 8 weeks) although slightly higher polythionate levels are developed in the presence of the ore sample. The 8 week results for the iodine iodide system are a little different in that I_3^- levels remain stable in the presence of kaolinite and hematite but drop approximately 20% in the first week and then stay essentially constant thereafter in the presence of goethite and the ore sample. However, the total iodine ($I^- + I_3^-$) remains constant, indicating that the loss of I_3^- is via a reduction step, most likely due to the oxidation of trace levels of an unknown component in the solid sample.

Ore characterization

Research into this, potentially new, mining method requires ongoing ore characterization studies in order to both understand hydrometallurgical test results and generate predictive numerical models of metal recovery.

A reconnaissance study of material from the samples used in the above hydrometallurgical tests was undertaken. The objective was to identify (1) the grain size range and mineral associations of gold particles in the ores and (2) possible permeability pathways for lixiviant to penetrate through to those particles. The automated SEM system chosen to carry out this study was QEMSCAN, an instrument which was originally developed by CSIRO in Australia (Goodall *et al.*¹⁶).

Thin sections were prepared for investigation using QEMSCAN. Each section was scanned for a total of one hour using a scan mode called SMS or specific mineral search. Under this mode, the machine is set to scan random fields (set to 350 micron 2) containing particles with a BSE or backscatter electron intensity value of >160 , with these particles confirmed as containing gold using x-rays. Fields identified as containing gold were mapped using EDS (energy dispersive spectrometry) x-ray analysis with a spatial resolution of 1 micron (necessary in order to resolve fine grained gold particles).

Coverage of the thin sections was approximately 30 area % for samples which contained no > 160 BSE intensity particles, but was significantly reduced to ~ 18 area % when one field was mapped using x-rays, and 6% with two fields mapped.

The images are useful as they show the textural context of the gold particles and indicate their proximity to fractures and pores, which in turn provide an indication of their potential accessibility/availability to the lixiviant. This study showed that the gold in the studied samples was located within or in close proximity to secondary minerals such as oxides (see Figure 4) and along fractures containing secondary muscovite and oxides.

Permeability enhancement

In general, the permeability of the host regolith material is quite low. Hydraulic conductivities encountered during general mine water supply and dewatering investigations by local hydrological consultants ranged from ≤ 0.1 m/day in

typical saprolite to 0.5–5 m/day in saprock. Nevertheless, gold-bearing zones may have hydraulic conductivities somewhat higher than the surrounding saprolite because the orebodies tend to be found in fault zones and the ore itself commonly consists of mineralized quartz veins. The latter may be quite permeable, especially along the vein margins or in cavities within them generated by the dissolution of carbonates or sulphides. In addition, any imposition of high stress to these ores (via blasting or application of hydraulic overpressure) is likely to result in fracture formation along quartz vein margins because of the high rheology contrasts present at such contacts.

There are three options under consideration for permeability enhancement. These are: (1) low intensity blasting, (2) hydraulic fracturing and (3) selective dissolution of gangue minerals.

Blasting

The use of blasting to enhance permeability is initially quite attractive. Blasting of the orebody is likely to enhance the permeability in directions associated with the deposition of the gold (i.e. supergene enrichment or quartz veining) as, when properly controlled, it opens up existing fractures and veins which contain the gold. In cases where the gold is included within grains, it is less likely to be effective.

For blasting, it is considered that a low density, high gas explosive offers the best method of achieving the opening of cracks and veins within the rock mass to allow the flow of lixiviant both to react with the gold and to flow from the injection point to the recovery point. The challenge then becomes restricting the effect of the blast to within the mineralized zone and to achieve the best flow direction of the lixiviant. Initial consideration of the concept suggests that blasting parallel with the long dimensions of the mineralization will achieve the best result with a greater proportion of the holes utilized for achieving the enhanced permeability.

The problem with blasting is that the blast is likely to damage both injection and recovery holes unless they are lined before blasting takes place. Correct alignment and location of holes will provide a simple and effective method of enhancing the permeability in a direction that will allow efficient recovery of the lixiviant.

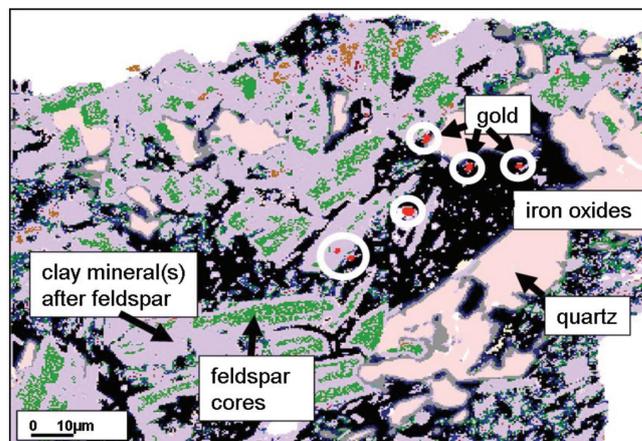


Figure 4. QEMSCAN imagery of gold-bearing saprolite from the Moolart Well deposit

Hydraulic fracturing

Over the past decade, hydraulic fracturing has been applied to preconditioning of ore to improve its caveability for mining. When applied for this purpose, hydraulic fractures are placed, from an array of boreholes, with a spacing along the holes that varies from about 1 to 3 m. The fractures are typically formed by injecting water at high pressure into a short section of the hole isolated by packers. The hydraulic fractures formed in this way have been measured to grow to 30 to 50 m in radius during the 20 to 50 minute long injection treatment. Therefore, the boreholes can be spaced at 35 to 80 m, which reduces drilling and fracturing costs. A similar approach to preconditioning is being considered here for the in place leaching method contemplated here.

The general process of hydraulic fracturing involves injection of fluid at pressures that exceed the minimum principal stress, typically by 1 to 3 MPa. The pressure used is sufficient to open and extend the main hydraulic fracture. As the fluid flows into and along the main fracture, part of it is lost from this channel into the surrounding permeable rock mass. This lost fluid increases the pore pressure in the rock surrounding the hydraulic fracture, leading to reduced effective normal stress acting on natural fractures in that part of the rock mass. The reduced normal stress, in turn, results in some increase in aperture of the natural fractures and can promote shear displacement and shear induced dilation on the natural fractures subject to sufficiently high shear stress. The permeability of the natural fractures affected by these deformations is increased as a result. Other changes to the rock strength and permeability may occur through chemo mechanically enhanced growth of micro cracks in the rock material. The rock volume around the hydraulic fracture is subject to elevated mechanical stress, imposed on it by the opening of the hydraulic fracture, and to elevated pore pressure as a result of the diffusion driven leakoff process.

Hydraulic fracturing can then be expected to provide a method to create discrete fractures extending to 10s of metres at regular spacing along each borehole and to promote shear and opening displacement in the surrounding rock mass (as permeability increases). The main hydraulic fracture channel is often propped open, using a permeable sand propping agent, to maintain a high permeability conduit in the rock mass after the pressure is dissipated.

The amount and location of permeability enhancement that can be obtained by a hydraulic fracturing process requires study. However, the application of hydraulic fracturing to precondition an orebody for the in place leaching method under consideration, seems feasible.

Selective dissolution

Orogenic gold mineralization is commonly closely associated with sulphides, most commonly pyrite. In most instances, pyrite weathers to form hydrated iron oxides, predominantly goethite within oxidized regolith. Goethite is soluble in hydrochloric and other acids and, therefore, one possible route to permeability enhancement and/or exposure of otherwise occluded gold grains would be to inject acid into the ore zone. Given that this would lower groundwater pH in the immediate ore environment, a subsequent stage of alkali injection, possibly sodium hydroxide, would be required to restore the pH to a level where the lixiviant is stable. This would be of particular importance if sodium thiosulphate was to be used, but may not be necessary in the case of the iodine system.

Acid injection may have environmental implications especially with regards to impacts on the surrounding groundwater both during metal extraction and afterwards. The method of ensuring that extraction rates exceed injection rates so that external ground water is drawn towards the extraction well(s) would need to be employed. Some other methods for mitigating any effects on the groundwater chemistry may also need to be considered.

Reactive transport modelling

The reactive transport modelling seeks to provide a quantitative framework to integrate the key physical and chemically reactive processes that affect the recovery of the gold from the subsurface. Specifically, the modelling is to explore the potential fate of the lixiviant in the ore deposit and the hydrogeochemical interactions that impinge on the in place leaching process envisaged here. This task is undertaken with the reactive transport model PHT3D (Prommer *et al.*¹⁷). The PHT3D code incorporates the solute transport simulator MT3DMS (Zheng and Wang¹⁸) and the versatile geochemical model PHREEQC (Parkhurst and Appelo¹⁹). The latter is capable of quantifying a wide range of either equilibrium or kinetically controlled reactive processes. The framework used allows one to conveniently adapt the numerical model to reflect the conceptual hydrochemical models describing the interaction of lixiviant, groundwater and mineral phases.

The main objective of the initial reactive transport modelling study was to identify the key research issues that may need to be addressed to overcome possible limitations of in-place leaching in the proposed setting of stranded gold deposits. In this respect, the first task has been to gauge the overall feasibility through an appreciation of the leaching times and fluxes of leaching solutions for an indicative injection and extraction scheme (optimization of the lixiviant injection and extraction scheme will be undertaken in later stages). For this purpose, a highly idealised scenario of a dipping mineralized quartz vein zone with a lateral dispersion of gold into the adjacent upper and lower saprolite, as well as saprock layers, has been constructed to form the basis of a numerical reactive transport model. This preliminary modelling study has focussed on a single nine well element of injection and extraction wells placed on a 12.5 m grid in the larger setting of the mineralized quartz vein and regolith. The larger domain was 500 m along the strike of the quartz veining and 100 m transverse to the quartz veining, extended to a depth of 63 m. Schematics of the layout of the wells in relation to the subsurface geology are shown in plain view and transverse vertical section through the quartz veining in Figure 5.

As a first pass, a simple gold complexation scheme was adopted in conjunction with idealized flow conditions (i.e. that for a homogeneous equivalent porous medium in the individual geological units) was adopted to evaluate lixiviant travel times and gold recovery times as well as fluid fluxes. This preliminary, simplified, reaction scheme consisted of an equilibrium complexation reaction of the gold in the presence of a generic lixiviant, i.e., the detailed kinetic reactions that are currently being characterised for the specific lixiviants were not yet used in this instance. The key hydrogeological parameters of hydraulic conductivity and porosity adopted for the different units are presented in Table II. The central injection/extraction wells were operated at flow rates of 20 m³/day and at an overall, neutral water/lixiviant balance.

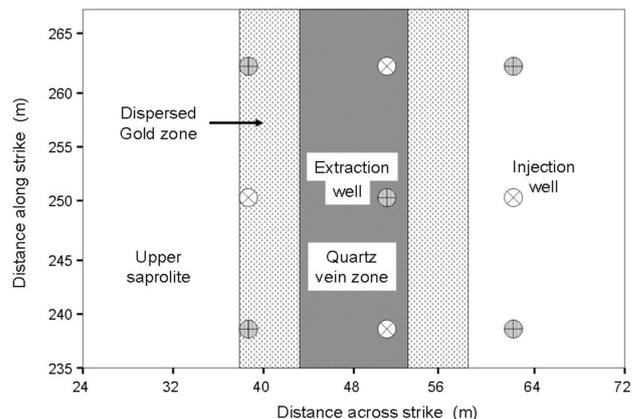
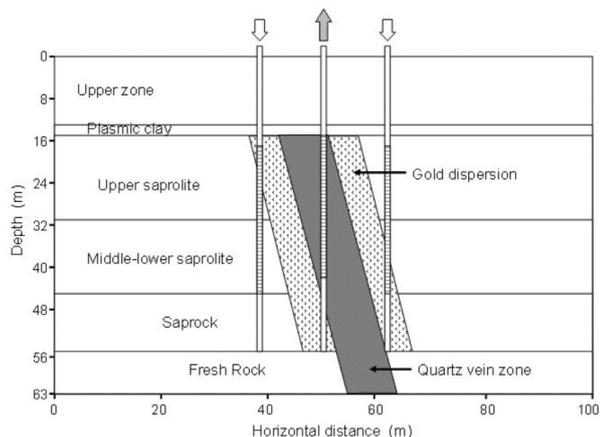


Figure 5. Transverse vertical section through the quartz veining showing a cross-sectional view of the geology implemented in the reactive transport model (above) and a horizontal section at the top of the saprolite showing the injection and extraction wells (below). (Note: the upper zone shown in section view in a complete profile would consist typically of an iron rich lateritic duricrust underlain by a mottled clay zone)

Table II
Hydraulic conductivities and porosities used for reactive transport modelling

Geological unit	Hydraulic conductivity K_x, K_y, K_z (m/day)	Porosity (dimensionless)
Upper zone	3/ 3/ 3	0.2
Plasmic clay zone	$1 \times 10^{-6}/ 1 \times 10^{-6}/ 1 \times 10^{-6}$	
Upper saprolite	0.01/ 0.01/ 0.01	
Middle-lower saprolite	0.01/ 0.01/ 0.01	
Saprock	1/ 1/ 1	
Fresh rock	2/ 2/ 2	
Zone of quartz veining	0.5/ 2.5/ 0.5	
Zone of gold dispersion	0.1/ 0.5/ 0.1	

Five cases were modelled using a range of lixiviant concentrations with the base case being that of the highest lixiviant concentration. Results of the simulations not unexpectedly showed that with a sufficiently high i.e. substantial excess lixiviant concentration there is a relatively efficient recovery of the gold from the deposit. The cumulative percentage recovery from a defined, control volume encompassing the injection and extraction wells is depicted in Figure 6. Breakthrough of the lixiviant and complexed gold within the deposit and in extraction wells (not shown) for the highest concentration case (base case) closely followed that of an inert tracer. This confirms that the presumably overly optimistic assumptions of this particular scenario characterize the idealized hydraulics of flow through the deposit without the complications of finer-scale heterogeneity, interaction of the lixiviant and gold, kinetics of the reactions and complexity of other geochemical processes affecting the leaching. Nevertheless, this simulation has already indicated the inaccessibility of portions of the targeted volume within a reasonable time frame. This suggests, further scope, for optimizing the well layout.

One of the key results was the overall time scale of the recovery. For the base case, this is of the order of months to one to two years. Further increased flow rates (and pressure gradients) would allow for accelerated recovery, but could potentially induce physical clogging problems.

The lower concentration scenarios successively progress to the situation where the lixiviant concentration limits the *in*

situ complexation of the gold. As a result, gold leaching occurs over a longer period, rather than being removed as a relatively sharp pulse when the lixiviant was in excess. The overall effect of the limitation by the lixiviant concentration, in relation to the increased time frame for leaching, can be seen in Figure 6. An interesting result is that the lower lixiviant concentrations are increasingly more efficient in terms of the mass of lixiviant needed to recover the gold present. This points to the possibilities of balancing the mass and cost of the lixiviant against the time for gold recovery to obtain maximum returns from the in place leaching operations under consideration here.

Discussion

The work described in this paper constitutes a reconnaissance study of a possible new in place leaching method for oxidized gold mineralization. The economic feasibility of such an approach has not been demonstrated for any specific gold deposit, however, a conceptual framework has now been established for evaluating the applicability of this approach to specific ore deposits.

Initial hydrometallurgical testwork suggests that at least two non cyanide lixiviant are capable of extracting high percentages of accessible gold from candidate oxidized gold ores under anaerobic conditions. Preliminary ore characterization studies suggest that, in some deposits at least, gold grains are located within iron oxides (commonly goethite) and that gold availability may be enhanced by an acid dissolution step prior to introduction of the lixiviant. Reactive transport modelling also indicates that, under most circumstances, artificial enhancement of bulk permeability will be necessary to obtain sufficiently fast break-through times for an economically successful leaching operation.

The research challenges encountered in addressing this problem are both complex and highly inter disciplinary. An ongoing multidisciplinary research program spanning several years is envisaged culminating in field trials at one or more mine sites.

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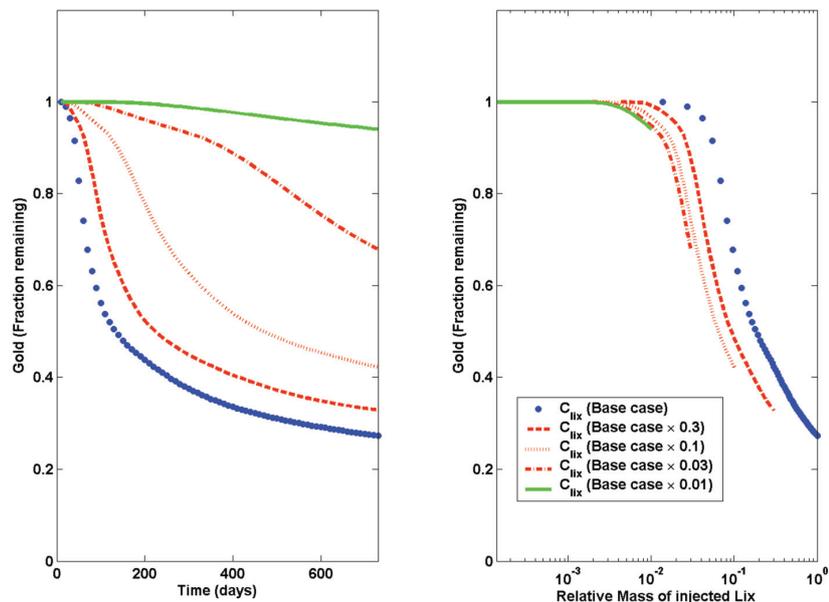


Figure 6. Gold remaining in the control volume of the nine well injection and extraction scheme as a function of time and relative mass of the lixiviant injected. (Note: relative mass = injected mass at a specific simulation time scaled by the temporally integrated mass in the base case after 730 days simulation time)

Specifically, we thank St Barbara Mines for assisting with sample collection at the Glendower and Cornishman mine sites near Southern Cross, Minotaur Exploration for the provision of samples from the Tunkillia deposit and Regis Resources for the provision of samples from the Moolart Well deposit.

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- Processing of gold using cyanide or thiosulfate
- Leaching and electrochemistry of gold and base metals
- Electrowinning
- Resin and carbon adsorption and elution
- Modelling and solution speciation
- Ion chromatography (for determining sulfur and cyanide speciation).