In-Situ Leach Mining
The Next Quantum Leap?

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ABSTRACT

This paper considers the opportunities and problems which in-situ leach mining technology presents to the mining industry. These are exemplified by concerns addressed in the development of a proposal to mine uranium by in-situ leach techniques at Beverley in South Australia.

INTRODUCTION

The nature and occurrence of many mineral deposits makes their mining by in-situ leach superficially an attractive proposition. The ever growing environmental regulations, plus community attitudes to the large excavation mining practices of the past also make solution mining an attractive proposition. Finally the energy economics of avoiding the excavation, movement and replacement of large waste rock (overburden) volumes in order to free relatively small quantities of valuable ore also makes solution mining an apparently attractive proposition.

In-situ leach technology can be traced back to the Frasch process of recovering native sulphur in the 18th century. Modern solution mining however commenced with hot water potash recovery in Canada in the 1950's which was followed soon after by uranium recovery in Wyoming in the United States.

In Australia solution mining has been practiced for potash recovery in Western Australia and has been considered in some detail for uranium ore recovery at Honeymoon and Beverley in South Australia; for gold at Eastville in Victoria and currently at several other locations in Australia.

TECHNOLOGY

Solution mining technology in its simplest form involves identifying a solvent which is specific and efficient in dissolving up the ore minerals present in an ore body. This is injected into the ore zone and drawn through to recovery wells from whence it is pumped as a pregnant lignor to an ore recovery plant. Here the liquor is stripped of its dissolved ore load before being retreated to generate further solvent for further ore recovery.

Solution mining wellfields incorporating lines of injection and recovery wells are advanced progressively across the ore zone preconditioning, leaching and rehabilitating it in a semi continuous operation.

In theory, at the far end of the operation the fields are abandoned and the ore zone stipped of its mineral wealth is left as an otherwise unaffected aquifer.

The prerequisites for successful solution mining are:

- amenable hydrological properties
- predictable mineralogical reactions
- contactable mineralization sites

With all these aspects being favourable the economics of the operation can be determined against ore reserves evaluated in the usual manner.

The major problems which solution mining has hitherto presented to mining companies have been

- recognition of the much increased definition which is required of the ore zone chemical and hydrological properties and

- recognition of the potential for large scale long term groundwater contamination and the difficulty of rehabilitating the environment.

HYDROLOGICAL PROPERTIES

Solution mining success is dependant upon the degree to which the solvents (lixivients) can be caused to move through and pervade all the void spaces in which mineralization may occur but they should not escape the ore zone.

The processes by which chemical pervasion occurs include velocity dependent advection; and dispersion, which includes permeability dependent hydrodynamic dispersion and chemical diffusion which is dependent upon chemical concentration gradients and equilibria.

Where poorly sorted, sediments exist, or where major variations occur in permeability across the mineralized zone (eg primary and secondary porosity and permeability) pervasion of the mass will be largely dependent upon dispersion and diffusion. Under these conditions it is essential to avoid high flow velocities and advective dilution, otherwise full pervasion and recovery may not ever be achieved.

A good evaluation of the hydrological properties applying is critical to design. This will often only be achieved by extensive carefully tailored hydrological testing across the ore zone, including multirate dye tracer tests and observation and sampling of large diameter cores (200-1000 mm diameter). Detailed geophysical logging can also be revealing, especially single point resistance, gamma density and neutron logs.

MINERALOGICAL PROPERTIES

The ore zone aquifer must be evaluated as a chemical mass and the reaction of each of the minerals present to the lixivient must be established as must the interactions which may occur. Clay, chlorite and felspar minerals present may be markedly changed by pH or redox potential variations, as may be the stability and reactivity of organic carbon, graphite and heavy metals present, especially iron.

At Honeymoon in South Australia, leaching with sulphuric acid and hydrogen peroxide lixivient failed because neutralization of the acid caused precipitation of gypsum and jarosite which blocked permeability in the aquifer adjacent to the injection holes.

Where cyanide leaching is involved, the solubilization of gold must be considered along with the solubilization of other heavy metals. Readsorbtion of gold preferentially on other minerals (eg carbon) in the flow path can then be a problem. Similarly, initial solubilization and subsequent reprecipitation of heavy metal carbonates and sulphates in the ionic "fractionisation" processes which take place at the leading edge of a lixivient front have caused coatings to form on the economic mineralization preventing their solubilization and recovery.

Where mineralization occurs in low permeability environments (sometimes referred to as "blind pores"), the permeation of these environments at the leading edge with low strength lixivient can render them buffered against further solution or prevent pregnant solution escape due to concentration gradients established and maintained by continuous ion flows from the lixivient on to gangue minerals eg H^+ ion adsorbtion on clays.

Laboratory experiments on cores at the surface can frequently identify and predict these reactions, but the experiments should carefully represent the solution mining environment. This must include lack of light, high hydrostatic pressure, temperature buffering and a lack of opportunity for gaseous exchange. Chemical and mineral equilibria diagrams under these conditions can be quite different from those generated under atmospheric conditions.

Similarly, the effects of exothermic reactions such as the oxidation of pyrite can create local convective circulation which may produce perturbations in mineral recovery and introduce delays into the system.

EXCURSIONS AND CONTAMINATIONS

A major problem identified in connection with solution mining is the possibility of lixivient excursions affecting the quality and amenity of adjacent or continuous aquifers. This in reality is less a problem than is perceived. The practice of overpumpage of the wellfield generally contains the lixivient. In practice few significant excursions have occurred and mostly they have been due to unsealed exploration holes. By far the major problems are the residual impacts of solution mining which must be addressed in aquifer rehabilitation.

AQUIFER REHABILITATION

In the early years of solution mining in the United States, aquifer rehabilitation or restoration was seen as a process of removing residual lixivient from the aquifer by either pumping to waste, stripping and recycling. It was rapidly found to be more difficult than expected. Where ammonia lixivient had been used the pumping could quite rapidly reduce the ammonia in return waters to acceptable levels. Once pumping ceased however, the changed concentration gradient and ion balances then applying, caused release of adsorbed ammonia and migration out of blind pores to recontaminate the groundwaters.

Similarly, mobilized organics, with complexed heavy metals, especially iron and manganese can cause the water to be highly contaminating and difficult to use for normal activities due to clogging and precipitation upon aeration.

These problems must be recognized at the outset and practical solutions found. Where solution mining is practiced within aquifers which have groundwaters with a realistic beneficial use, no regulatory authority is likely to permit the operator to depart the field leaving it impaired as to quality or productivity.

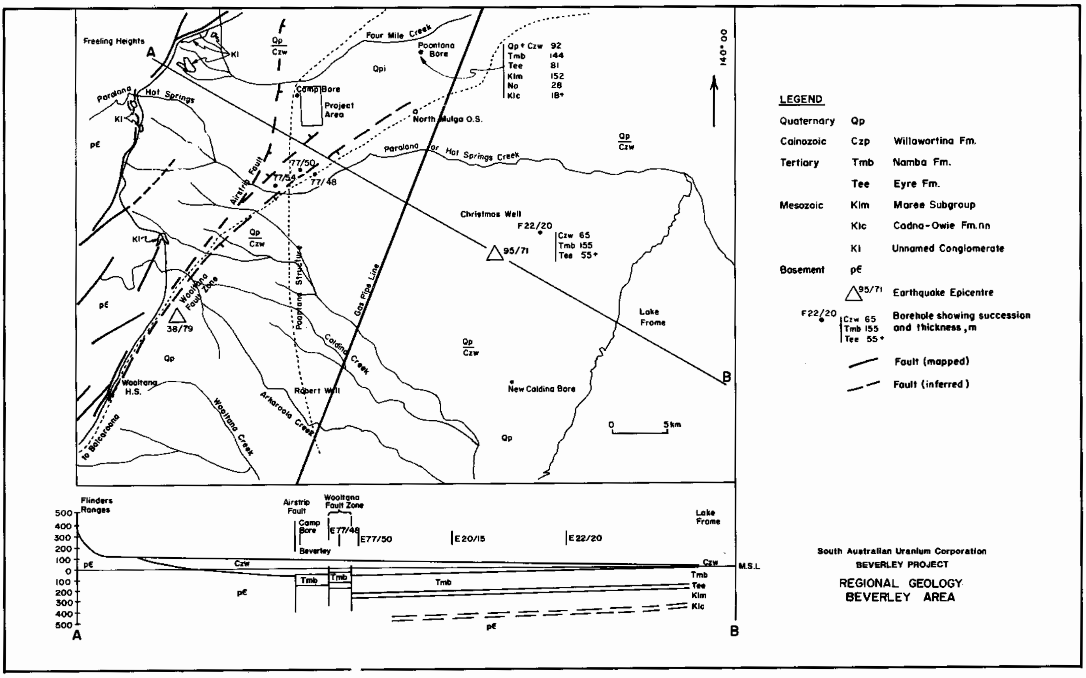
PROPOSED IN-SITU LEACH MINING OF URANIUM AT BEVERLEY, SOUTH AUSTRALIA

The Beverley Uranium Project is based upon a sedimentary (roll front?) uranium deposit in fluvio-lacustrine sediments of the Miocene Namba Fm. on the margins of the Lake Frome Basin adjacent to the North Flinders Ranges.

The mineralization is mainly in the form of coffinite with some uraninite. Sulphides are minor. A significant proportion of the mineralization occurs in permeable confined aquifers which exist amongst clayey deposits at depth between 100 and 140 m below land surface. These mineralized deposits are hydrologically confined by a dense, low permeability, illitic clay bed which varies in thickness from 5.5 to 27 m. This clay is defineable across the extent of the ore body by the characteristic trace it produces on geophysical log curves.

The overburden includes alluvial fan deposits of the Upper Tertiary Willawortina Fm., a semi confined to unconfined aquifer, which is used for stock water supply. Underlying the ore body is a thick sequence of shales and dolomite which form the major thickness of the Namba Fm. These separate the ore body from the other main aquifers of the region, the Palaeocene - Eyre Fm. and the Lower Cretaceous Cadna - Owie Fm.

Hydrogeological relationships in the area are complicated by structural deformation with faulting providing vertical hydrological interconnection between the deeper aquifers. Similarly, the shallower aquifer zones show complex recharge and hydrochemical relationships due to variation in recharge opportunity, discharge and flow patterns. These have created recharge mounds beneath creeks which have prevented water exchange in the mineralized sands.



All these aquifers are highly valued and the proponents have had to address the problems of aquifer protection during and beyond mining life very carefully. Conventional mining would have required major dewatering of the Willawortina Fm. aquifers and would have resulted in direct connection between that aquifer and the radio-active waters in the Namba Fm. upon cessation of mining. For these reasons it is proposed that the uranium resources be mined by in-situ leach.

The evaluations of the site involved high density drilling and coring with geological definition being obtained from geophysical log suites calibrated against detailed core logs and evaluations. Evaluations of the hydrology were undertaken by pump and slug testing. Careful examination of hydrogeochemistry and consideration of the in-situ leach chemistry as it would operate on the minerals in the aquifer and confining beds during and beyond mine life were carried out.

Computer modelling has been undertaken to test in-situ hydrological stress development during mining and careful core collection and handling was undertaken to preserve in-situ conditions so that detailed laboratory examinations and evaluation of hydrological properties could be performed.

The results indicate that the mineralization has been protected from natural dissolution by the orientation of the mineralized sands, by structural controls and by the recharge mounds deriving from the streams at either end of the ore body.

In-situ leach mining technique proposed will use sulphuric acid with hydrogen peroxide or dissolved oxygen as the lixivient. Pre-treatment of the aquifer will be necessary to remove excess calcium carbonate, and the system will employ a slightly overpumped output of fluid through the wellfield to reduce the risk of excursions of mining solutions. The input and output patterns will also be varied to take account of the hydrogeological conditions such as confining bed thickness and permeability.

Much study has been directed towards the post mining condition of the ore zone and the threat it may pose to the water resources of the region. This has involved consideration of the realistic value of water and the aquifers in the area and detailed consideration of the physical and chemical reactions consequent on mine cessation and the monitoring and management of these.

The mineralogy of the clays and sands include exchangeable and soluble calcium and carbonate which will act to both neutralize acids and cause gypsum precipitation when a spent sulphuric acid leachate moves into unconditioned material. These, plus the presence of continuous, regionally extensive, dense, clay layers both overlying and underlying the mineralized zone preclude significant chance of leachate escape.

Problems of improperly sealed exploration drill holes remain to be resolved and operational optimization of both mining and rehabilitation techniques awaits the pilot testing stage. The proponents and their consultants are confident that in-situ leaching at Beverley can be conducted without the many problems which have been encountered or attributed to the originators of this mining technique in North America.

CONCLUSION

The apparent simplicity of solution mining, coupled with its apparent environmental and energy benefits makes it an attractive alternative to conventional mining in many instances. The complications and problems however arise in defining and managing the natural system chemistry.

Where the hydrogeological environments are insensitive in respect to realistic beneficial uses of the groundwaters after mining at least some of the problems are removed, but where the groundwaters occurring in the ore zone are intrinsically valuable, as much care must be taken at the outset to ensure that not only can the economic minerals be recovered efficiently, but that effective rehabilitation of the aquifer is possible within the project economics.

Much has been learned from the experiences of the solution mining operations undertaken to date but every site has its own peculiarities and these must be engineered and managed both chemically and biologically to ensure that the problems left behind are not worse than might have been confronted had conventional mining techniques been employed.

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