Groundwater inflows and management at Emily Ann and Maggie Hays underground nickel mines, Western Australia

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ABSTRACT

LionOre Australia (Nickel) Limited operates two nickel mines in one of the belts of ultramafic rocks in the southern part of Western Australia. Emily Ann has been in production since 2001 and had reached a depth of 220 m by early 2003. Maggie Hays, some 7 km away, commenced development in January 2003, in a nearly identical geological setting.

The main orebodies are steeply dipping, massive sulphides, disseminated in places, with an ultramafic footwall and a hanging wall of felsic volcanic rocks. Underground development at Emily Ann has been by box cut and decline, mostly within the felsic volcanic rocks, which have good characteristics for underground excavation. In contrast, the ultramafic rocks are typically poor in strength and structural characteristics, common features in Western Australian settings.

The groundwater is saline and, before mining, occurred below depths of 22-25 m at Emily Ann. Inflows have occurred from the initial box cut down. The box cut was dewatered by bore pumping and sumping. Inflows occur mostly through the felsic volcanics, predominantly through a set of shallow dipping joints with extreme variability in hydraulic conductivity, ranging from tight and "dry" to open, with individual inflows over short distances of some 5-10 L/sec. Some control of inflow rates and groundwater levels above the deeper workings has been achieved using pumped wells.

There is a broadly linear relationship between inflow rate and depth at Emily Ann and, following a programme of core drilling and packer testing which confirmed the geological similarity and great variability in hydraulic conductivity, this relationship was used to predict inflow rates for Maggie Hays. Dewatering design and costing has been based on the extrapolated Emily Ann data.

After settling, mine water is discharged to a salt lake, typical of many in the region.

PART ONE – BACKGROUND

INTRODUCTION

Two nickel orebodies are being mined in separate underground operations by LionOre Australia (Nickel) Limited in south western Australia. The mines are located about 450 km east of Perth, the capital city of Western Australia.

Mining is by cut and fill, with a cementitous crushed rock backfill. Access development is by means of a decline, the position of which has been controlled largely by geotechnical requirements for portal location and avoidance of known poor quality ultramafic rocks.

Groundwater inflows to the Emily Ann mine, which has operated since 2001, show some interesting structural controls and have been used as a guide to future inflows to the similarly hosted Maggie Hays deposit. The Maggie Hays mine is currently being developed, the decline being about 150 m below surface at the time of writing.

CLIMATIC AND GEOGRAPHIC SETTING

The climate of the Lake Johnston Operations area is semi arid, experiencing warm to hot summers (average daily temperature range 15.8 to 32.5ºC) and cool to mild winters (average daily range 5.2 to 16.6ºC). The average annual rainfall is approximately 290 mm, generally distributed more consistently within the winter months and usually associated with cold fronts from sub Antarctic low pressure systems. Summer rain occurs either from thunderstorms associated with pressure troughs, or from degenerated tropical cyclones. The latter are capable of generating storm events with rainfalls up to 160 mm.

The topography is gently undulating with higher ground separated by poorly defined water courses subject to sheet flooding. There are no major drainage channels, and the only regional surface water features are the salt lakes Lake Johnston, Lake Hope and their satellite lakes, all located at least 10 km south of the Maggie Hays deposit (Figure 1). These lakes constitute evaporative discharge areas for regional surface and groundwater flow.

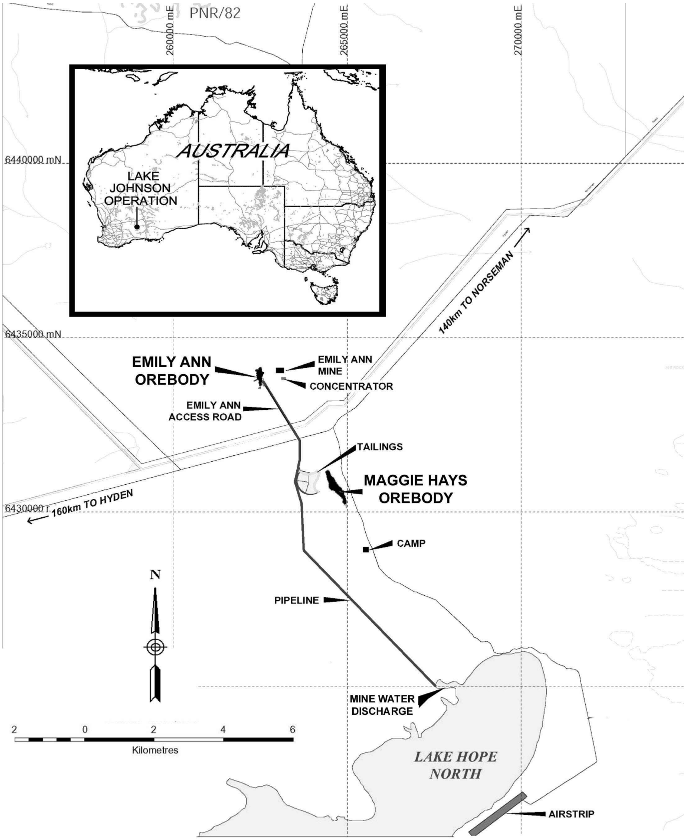

Figure 1: Locality and layout plan

Vegetation in the immediate vicinity of the mines is dry sclerophyll woodland (*Eucalyptus* and *Melaleuca*), with mallee woodland, scrub heath and broombush thicket being found further afield.

GEOLOGY

The nickel deposits are located in the informally named Lake Johnston Greenstone Belt, part of the Southern Cross geological province within the Yilgarn Craton. The rocks in this province are Archaean in age (2.5 to 3.1 Ga) and include granitoids, gneiss and greenstones with multiple deformation events. This setting is typical of many throughout the craton, across a large part of Western Australia.

The dominant regional structural trend is north-north west, with many major faults and shear zones parallel to this trend. Cross cutting the regional structural trend is a series of northeast-southwest trending faults. Mafic dykes were intruded in late Proterozoic time in an approximate east-west direction, possibly coincident with the principal stress direction in the rock mass.

The near-surface geological environment includes thin transported and lacustrine clays, lateritic ferricretes and a variably thick weathered zone. Over most rock types, particularly the felsic volcanics, there is a typical saprolite profile (Figure 2). Over the ultramafic rocks, a vughy and siliceous caprock has developed, typical of the region. These transported and weathered materials range typically from 35 m to at least 100 m in thickness, although there is sporadic outcrop, particularly of banded iron formations. Mine decline access portals have been located where sound rock could be found at shallowest depth near each deposit.

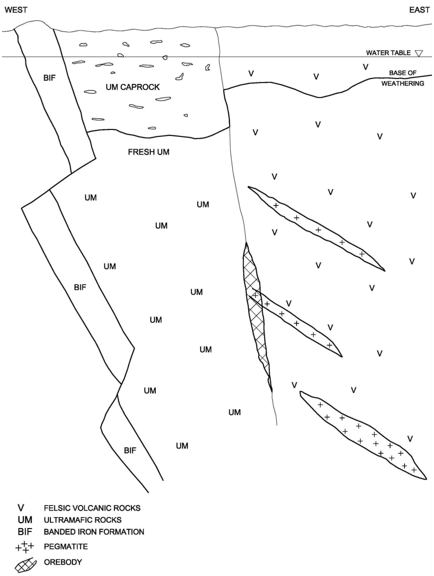

Figure 2. Diagrammatic geological section

Most mineralisation is hosted within ultramafic and/or felsic volcanic rocks, which occur within granite-gneiss terrain. Locally the deposits are flanked by felsic volcanic suites to the east, with mafic rocks and banded iron formations to the west. Intrusive pegmatites and mafic dykes are common.

Mineralised zones in both deposits have north west – south east strike lengths of 1 to 1.5 km and extend to depths of approximately 500 m.

The mineralisation is sulphidic, with both massive sulphide bodies, which are broadly tabular and structurally complex, and zones of more disseminated mineralisation.

REGIONAL HYDROGEOLOGICAL SETTING

Groundwater is saline within the region. At Emily Ann the pre-mining water table was about 22 to 25 m below surface, and at Maggie Hays the water table is about 28-30 m below surface, both within weathered material.

The regional groundwater system is characterised by slow movement towards discharge zones in various salt lakes, where the water is lost by evaporation and salt crust and groundwater brines are forming.

Recharge rates have not been investigated in this specific area. However, based on research over some decades in similar climatic settings in Australia, we interpret the recharge rates as being probably no more than about 1 mm per year. Mine dewatering therefore will cause a lowering in groundwater levels that will not be affected seasonally.

There are no users of the saline groundwater within tens of kilometres and the effects of dewatering are regarded as not having an environmental impact.

Aquifer transmissivities, as indicated by test pumping during the feasibility study for both Emily Ann and Maggie Hays deposits, and experience-based judgement, are variable. These transmissivities range from negligible in some weathered materials, fresh ultramafic rock, the orebodies and probably the intrusive rocks and banded iron formations, to approximately 10 to 100 m^3/day/m in the ultramafic caprock and the felsic volcanics. This strong contrast in properties means that inflows to the stopes where ore is mined should be small, except where drillholes were not plugged during early exploration activity. However, significant inflows are expected, and have occurred, within the felsic volcanics at Emily Ann.

MINE WATER DISPOSAL

The saline water that is pumped from the mine is passed through settling ponds then discharged to Lake Hope, one of the region's many salt lakes. This is a common approach in Western Australia, where environmental approvals have been given in cases where metal concentrations are low.

In the longer term, mine water discharges to salt lakes are attracting greater scrutiny and there is growing pressure for these discharges to be minimised.

PART TWO – EMILY ANN MINE

EMILY ANN MINE DESCRIPTION

The Emily Ann mineralisation is accessed via a boxcut and portal within a basalt dyke, located to the east of the mineralisation. From the portal, the decline runs west within felsic volcanics and below weathered material. The decline intersects the orebody at approximately 120m depth.

The orebody consists of two surfaces, thought to be part of a fold, and is thickest where the surfaces meet. It is complex due to later faulting and shearing.

The Lower ore zone plunges 25 to 30º to the northeast, is undulating, and sometimes comprises multiple massive units, separated by ultramafic host. The Lower ore zone is mined by room and pillar methods with backfill.

The Upper ore zone has a variable dip but on average plunges 60º to the northeast, is thinner than the Lower ore zone, and is hosted in ultramafics. The Upper ore zone is currently mined by drift and fill methods. However the lower parts of the Upper ore zone are likely to be mined by long hole open stoping methods.

Groundwater entering the mine workings is either pumped up the decline, or up a vertical rising main, to surface settling ponds for removal of sediment and hydrocarbons, prior to joining the surface mine water circuit.

MINE WATER MANAGEMENT

Initially, mine water management at Emily Ann was approached using dewatering bores, since early investigations indicated high rock mass hydraulic conductivities. The dewatering bores did have some effect on the rates of groundwater inflows to the mine but they by no means prevented such inflows.

Currently, production bore pumping is used mainly to provide a clean water supply to the mill, where sulphide concentrate is produced, and most mine water is pumped directly from the mine by means of temporary and permanent pumping stations.

A current extension to the main decline has been investigated by cover drilling, which did not indicate large inflows.

HISTORY AND CHARACTERISTICS OF INFLOWS TO THE EMILY ANN MINE

Groundwater was encountered at Emily Ann during the construction of the access box cut and portal. This situation was managed with nearby dewatering bores. Further dewatering bores were installed along the planned alignment of the access workings, which, because of the adverse ground conditions in the ultramafic rocks, were developed within the transmissive felsic volcanic footwall rocks.

Dewatering bores had a beneficial effect in reducing the rate of inflow to Emily Ann during 2000-2003, but they did not prevent inflows. None of these bores are now being used for dewatering purposes.

Figure 3 shows the record of mine water pumping versus depth for the mine.

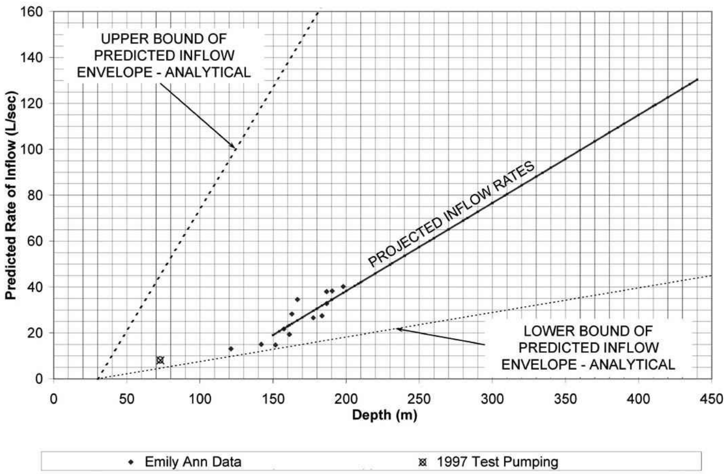

Figure 3. Emily Ann mine inflow data and projected inflow rates

Typically, most of the rock mass exhibits low hydraulic conductivity, with small or no inflows. However there are distinct zones within which inflows of the order of 5-10 litres/second emerge from a set of shallow, south-westerly dipping fractures. These fractures are heterogeneous, ranging from open (widths of as much as 10-20 mm have been observed) to tight within distances of a few metres. Some inflow zones also exhibit inflows through rock bolts, indicating that groundwater pressures remain significant within a few metres of the mine opening in the vertical direction. Similarly, a few zones in which large inflows have been observed from blast holes in the decline face show that fractures within a few horizontal metres can retain pressure. Not unusually for fractured conditions, the rock mass is heterogeneous.

The inflows and fracture characteristics are indicated on Figure 4.

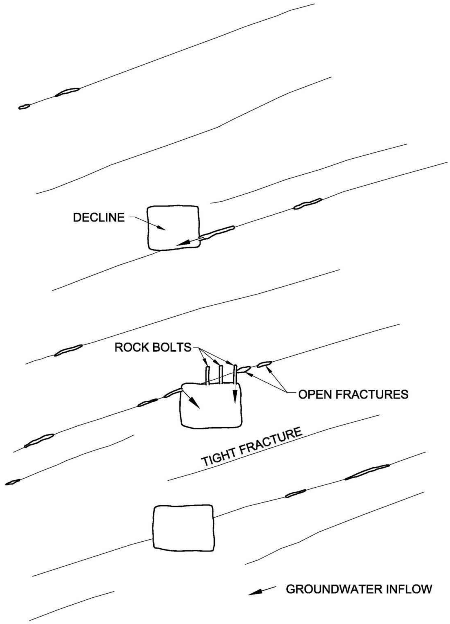

Figure 4. Emily Ann Mine, schematic section through access development showing groundwater inflows

Overall, the rock mass shows a strong anisotropy, with horizontal hydraulic conductivity greater than vertical. This anisotropy is shown, for example, by:

- the persistence of joint-controlled inflows long after there has been nearby development to greater depths
- strong groundwater inflows from short rock bolt drillholes in the decline roof.

The anisotropy is caused by the relatively high hydraulic conductivity within the shallow-dipping joint set in comparison with poor vertical interconnection between those joints.

PART THREE – MAGGIE HAYS DEPOSIT

MAGGIE HAYS FEASIBILITY STUDY

During 2002, the feasibility of mining the Maggie Hays deposit was investigated. Early in the assessment, similarities between the geological settings of the two deposits were recognised as providing an opportunity to assess the likely groundwater conditions at Maggie Hays by reference to the actual behaviour of groundwater at the Emily Ann mine.

A programme of ore reserve delineation drilling during 2002 provided an opportunity for hydraulic testing of the Maggie Hays deposit down to depths of about 400 m. It was decided to integrate a programme of packer testing and geotechnical logging of the core. Test pumping was judged not to be practicable approach, given the depths to which mining was likely and the heterogeneity of the fracture permeability at Emily Ann. Initial review of information available for Maggie Hays did not provide confidence that deep test pumping wells had a reasonable probability of providing representative information.

The approach that was adopted was therefore to use downhole packers to isolate selected test intervals in footwall, ore zone and hanging wall rocks, with some intervals also selected to test fracturing that was identified during geotechnical logging.

In summary, the results showed low hydraulic conductivities (10^{-6} to 10^{-3} m/day) in all rock types other than the felsic volcanics, where hydraulic conductivities as high as 1.5 m/day were indicated. This result is essentially the same as shown by mine observations and test pumping results for the Emily Ann deposit.

PREDICTED INFLOWS TO THE MAGGIE HAYS MINE

Figure 3 shows predicted rates of groundwater inflow to the Maggie Hays mine, as a function of mine development depth.

Inflows were predicted in two ways:

- by extrapolation of the data for Emily Ann inflows, given their geological and hydrogeological similarities
- by use of analytical approaches for calculating steady state inflow rates, using high and low estimates of hydraulic conductivity and regarding the spiral decline sections as large diameter wells and using standard tunnel inflow equations for the interconnecting straight decline.

The Emily Ann extrapolation lies near the middle of the envelope provided by the analytical equation inflow estimates, and this line of predicted inflow versus depth was used to design pumping systems to the feasibility level, for the purpose of estimating both capital and operational pumping costs. Figure 5 presents a schematic diagram of the mine water management system adopted for the feasibility study.

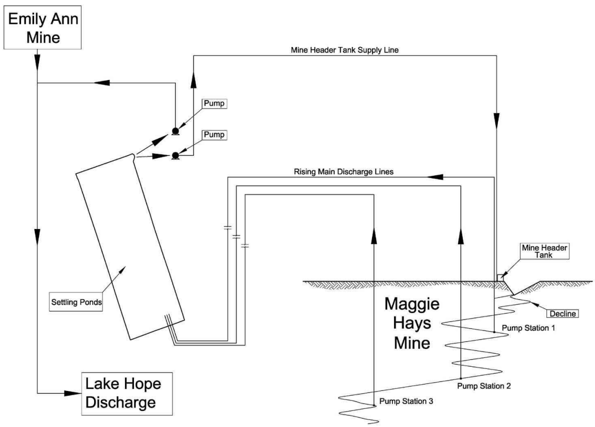

Figure 5: Schematic diagram for Maggie Hays mine water discharge

CONCLUSION

During recent studies on the feasibility of mining the Maggie Hays nickel deposit, early recognition of the similarities in hydrogeological setting of the nearby Emily Ann nickel mine and the Maggie Hays deposit, lead to the use of The Emily Ann mine as an analogue for estimating the groundwater inflows into the Maggie Hays mine.

Opportunistic packer testing of Maggie Hays resource delineation drillholes confirmed the similarities between the two deposits and the relationship observed at Emily Ann between groundwater inflow and mining depth was subsequently used to estimate capital and operating pumping costs at Maggie Hays.

Ongoing monitoring of inflows to both mines will with time, show the validity of this conclusion.

ACKNOWLEDGMENTS

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