OPERATIONAL AND ENVIRONMENTAL WATER PROBLEMS AT MARINERS UNDERGROUND NICKEL MINE, KAMBALDA, WESTERN AUSTRALIA.

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ABSTRACT

Mariners underground nickel mine was operated from 1991 to 1999. The mine was one of several in the Goldfields of Western Australia, operated by Kambalda Nickel Operations (KNO - a division of WMC Resources), until its closure in April 1999. During 1997 groundwater inflows to the mine increased from less than 10 l/s to more than 40 l/s, following a series of hanging wall failures.

The extra costs of pumping, disposal, remediation and investigation put a significant strain on the economics of the mine. The hypersaline nature of the groundwater (up to 280 g/l salt) was significant in determining the environmental impacts of the excess water disposal.

Groundwater investigations involved the development of a conceptual model of the aquifer system, surface geophysical testing, potentiometric surface mapping in the key aquifer and exploratory drilling and testing from underground. A separate investigation of water disposal options resulted in temporary operation of a water injection system at a remote location.

BACKGROUND

Mariners mine is located 120 km south of Kalgoorlie, on the vast Western Australia shield (Figure 1). Locally the land surface is slightly dissected, with elevations in the range 280 to 440 metres. The area is vegetated with a sparse eucalyptus woodland and the low country dotted with salinas (normally dry, terminal salt lakes) of all sizes. Mariners mine is located underneath one such lake, Lake Zot. The climate is semi-arid, annual rainfall is about 280 mm, with pan evaporation about 2700 mm. Most of the rain falls in the cooler months of June, July and August, although in some years there is significant summer rain from cyclonic-type events and thunderstorm activity.

Surface infrastructure for the mine is located on a small island west of the deposit. The development decline spirals down in the footwall Basalt with short ore access drives through to the ore body, which is mined by sub-level caving. There is a localised network of surface causeways on the Lake bed to allow access to wheeled vehicles, as the superficial sediments remain saturated and soft throughout the year.

GEOLOGY

Mariners is situated in the Archaean Yilgarn Craton of Western Australia, on the southeast side of the Widgiemooltha Dome beneath Lake Zot, an ephemeral brackish playa lake.

Nickel sulphide mineralisation occurs on a north-striking basalt - ultramafic contact with an overall dip of about 60 degrees to the east. At the centre of the deposit the main mineralised contact (010/60E) is truncated at about 50m below lake

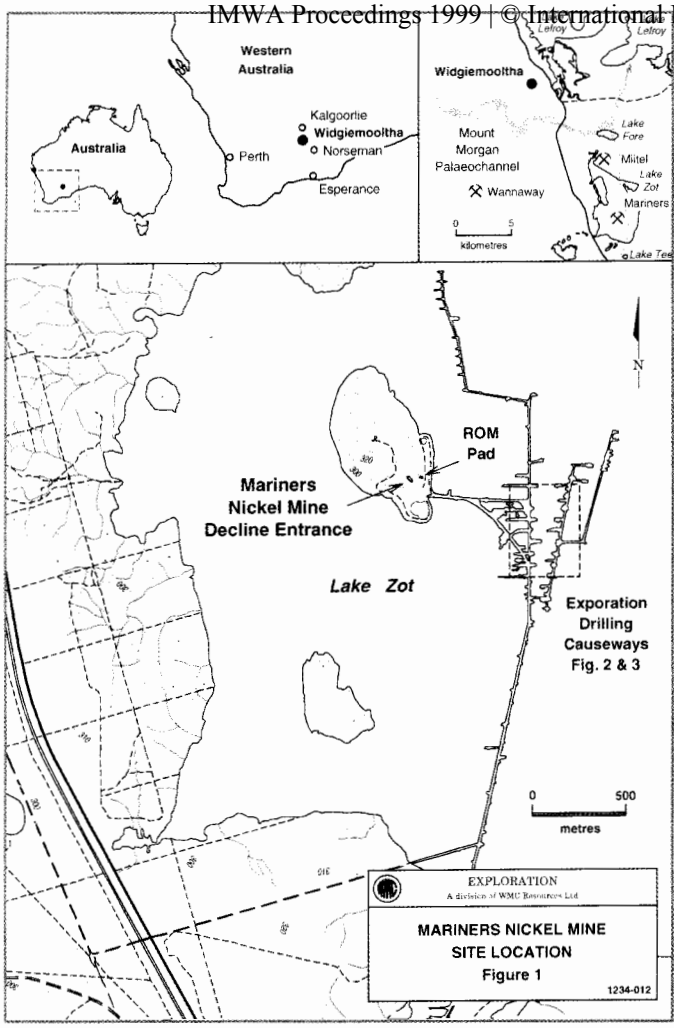

Figure 1. Site location.

level by the Albatross Fault (010/45E) where the Ultramafic is downthrown to the east. A series of NNW and NNE trending dextral wrench faults cause the mineralised zone to be broken into a series of en-echelon ore surfaces which plunge to the NNE (Figure 2). The geometry of interflow sediments (Chert) in the hanging wall is complicated by deposition and structural discontinuity, with the effect that thin bands of Archean sediment occur almost randomly over an 80 m thickness above the Ultramafic (Figure 3).

Unconsolidated Tertiary to Recent fluvial sediments thicken east across the deposit from 1-2 m over the basalt, to 30 m at the easternmost causeway. Depth to base of complete oxidation similarly increases from 5 to 50 m eastward. Immediately east of the deposition the Tertiary sequence reaches a maximum thickness of 40 metres and includes up to 10 metres of moderately permeable sands.

GROUNDWATER OCCURRENCE

From the start of development in 1991 to 1995, discharge of water from the mine was intermittent and averaged only about 1 l/s. Following major hanging wall failures in January, April and August 1997, flows increased from less than 10 l/s to more than 40 l/s. The increased inflows first appeared from inaccessible stoped-out areas of the upper ore surface, meaning the precise area of inflow was unknown.

There is no seepage from the footwall Basalt. Natural permeability within the deeper Archean rockmass is limited to contact and fracture zones, above the Basalt. Most such geologically significant features are sub-vertical and sub-parallel to the regional strike. Bands of sediment, within the hanging wall are likely to be much more permeable than other rock types and may constitute an extensive and interconnected aquifer - this would have no natural connection to the mine workings due to stratigraphic separation.

Drilling through the regolith profile at 20-50 m depth showed a highly variable zone, and in some areas a well developed secondary porosity and high permeability. The trough of Tertiary sediments to the east contains high storativity materials of low to moderate permeability.

CONCEPTUAL MODEL

The trough of Tertiary sediments immediately east of the mine provides a large a storage of groundwater which can sustain inflows to the mine. This storage is seasonally replenished by winter rainfall collected on the surface of the Lake.

On a broad scale the regolith aquifer provides, for the lateral transmission of water from the Tertiary materials west towards the mine workings. The nature of the leakage through from the regolith aquifer to the underground workings was the primary subject of investigation, although the history of inflows show that it was mining-induced.

Initially it was thought that an old exploration drillhole

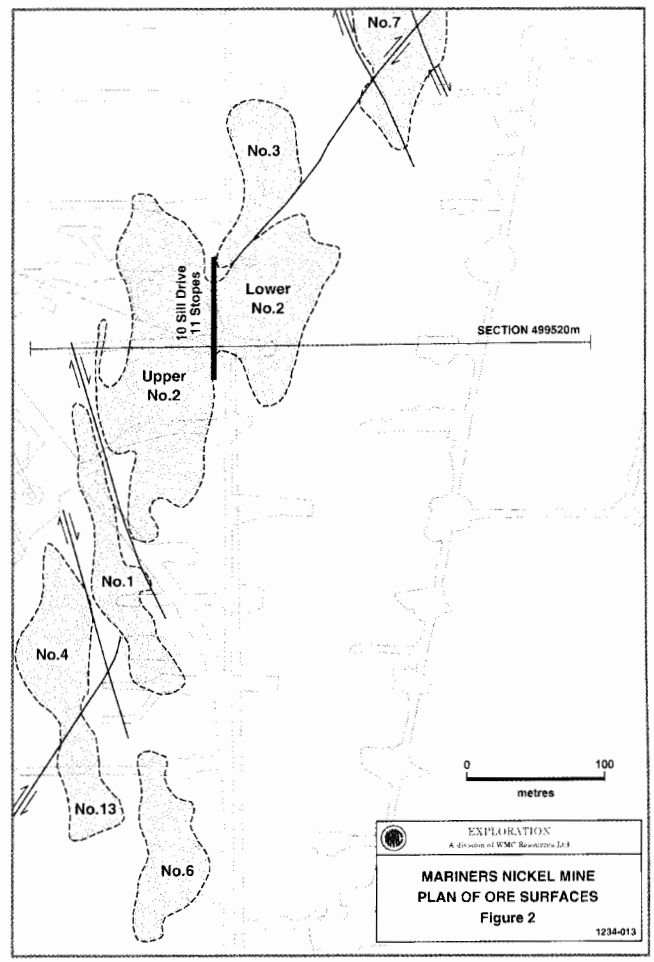

Figure 2. Plan of ore surface.

was the main conduit linking the regolith aquifer to zones of techno-genetically induced permeability in the hanging wall. Since extensive exploration had already been done prior to KNO's purchase of the property there was little confidence in records and practises of grouting of exploration holes after completion by the previous operator. A programme of re-drilling and completely grouting old exploration drillholes which intersected the ore surface near the hanging wall failures was undertaken but as this did not reduce the inflows and specialist hydrogeological help was sought in defining the nature of the leakage.

All exploration drillholes were drilled NQ size, which have an estimated full-bore capacity of about 20 l/s, so that the inflows of 45 l/s would require two such holes. Since none had been found, the mechanism was somewhat discounted as a likely cause.

WATER CHEMISTRY

In September 1997, a hole was drilled through the Tertiary and regolith aquifer sequence to a depth of 55 metres. Eight samples were taken and compared to five comparison samples from within the mine. Water chemistry from the regolith zone aquifer was somewhat distinct from that of the sediments and very similar to that sampled from the mine. Characteristic parameters were stable isotopes and salinity.

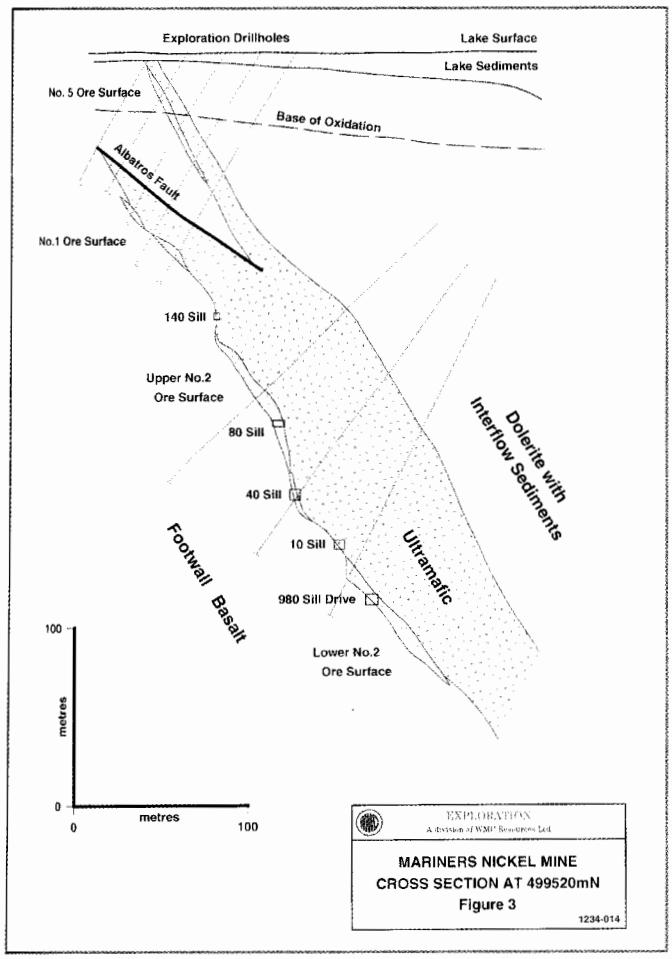

Figure 3. Cross section.

GEOPHYSICAL SURVEYS

Gravity and EM surveys were undertaken on the Lake bed in November 1997. The surveys were aimed at identifying any specific bedrock or sediment features. The results confirmed the general conceptual model of the area but did not indicate any specific features worthy of follow-up drilling.

UNDERGROUND DRILLING 1

In November 1997, two holes were drilled from the 190 level (100 metres depth) through the hanging wall and Albatross fault at the southern, up-plunge end of the deposit. The Fault zone was found to be silicified and of low permeability but sympathetic faults in the hanging wall yielded moderate flows. Static pressures were only about 12 metres below Lake level (pre-mining static water level) and dynamic tests indicated the fractures were not laterally extensive.

REGOLITH AQUIFER POTENTIOMETRIC SURFACE 1

From March 1998 a network of surface piezometers was established to map the cone of drawdown in the upper regolith aquifer, with the intention of using this to locate the zone of leakage through to the workings. Difficult drilling conditions and lack of access hampered the work which was not completed until late in April. The Lake was inundated with runoff from early winter rains at this time and infiltration through the Lake bed affected the shape and magnitude of the drawdown cone, such that it was not accurately identifying the area of leakage.

Despite this, the preliminary map of drawdown in the regolith aquifer did show that the cone of drawdown was centred out over the hanging wall, significantly east of the crown pillar of the mine, where the Albatross Fault converges with the mine workings.

Two deeper holes were drilled from surface in the area of the cone of drawdown. Static and dynamic tests did not strongly support the presence of significant downward throughflow in the deeper rock mass in this area.

WATER DISPOSAL BY INJECTION

Routine mine water disposal from Mariners mine was by pumping to Lake Fore, a small isolated salina 5 km north of the mine. During mid-1998 it was recognised that winter run-off combined with the water discharged from the mine, had the potential to raise the Lake level to its capacity, and an alternative disposal mechanism was sought.

Previous water supply investigations had delineated a major regional hypersaline water-bearing palaeochannel aquifer located adjacent to Lake Fore, with the potential for aquifer injection disposal. Following geological and geophysical investigation, it was decided to establish a trial injection system to

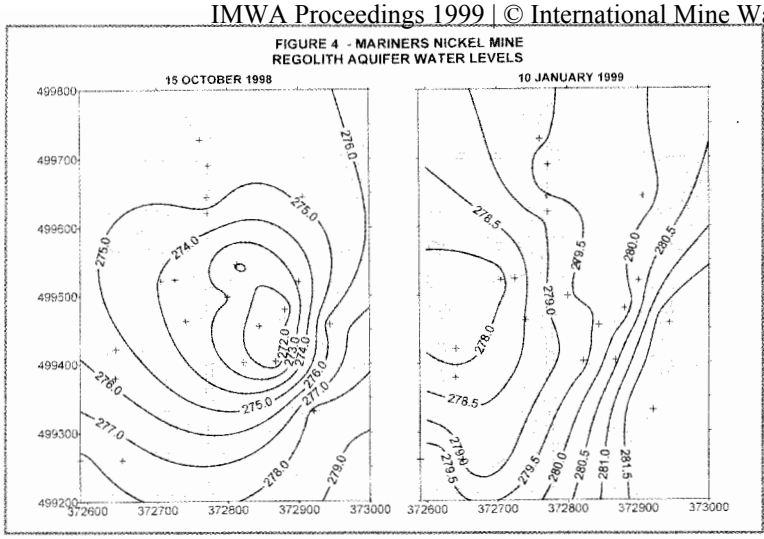

Figure 4. Regolith equifer water levels.

determine the viability of this alternative. Three bores were drilled through the Tertiary sedimentary sequence and screened in basal thick, coarse grained sands. The bores initially operated at rates of up to 15 l/s each but gradually lost efficiency due to clogging from fine sediment mobilised by wind-action on the shallow lake surface. Backflushing only partially restored bore efficiency. This is perhaps due to the extremely fine, talcose material discharged with the mine water, which may have travelled a significant distance into the aquifer and flocculated in situ.

Despite the decreasing bore efficiency, the injection system operated through the late winter period as a disposal method. Injection was halted when the excess of evaporation over discharge again began to control the Lake level.

REGOLITH AQUIFER POTENTIOMETRIC SURFACE 2

From October 1998 the Regolith aquifer water levels were in seasonal recession. This allowed the emerging water level pattern to show much better resolution than during the winter period of high water levels. The centre of the cone of drawdown was now more localised and associated with the trajectory of a single old exploration drillhole DRD250 (Figure 4).

Previous and renewed efforts to re-enter and grout this hole were unsuccessful, with the drill string wandering off the hole due to obstructions. It was decided to drill a piezometer onto the trajectory of the hole to confirm the leakage path. As the hole was drilled and cased through the target zone a marked reduction of inflows to the mine workings occurred. The drilling had partially blocked the hole and the annular sealing materials used in construction of the piezometer had also added to the seal.

METERING OF MINE DISCHARGE

After ongoing problems and little success using mechanical flow meters on the numerous small discharge pipes, the discharge system was re-configured. From late October 1998 there a single large diameter discharge pipe with reliable ultrasonic metering of flow rates was installed. The flows into the mine were already in recession at this time, and continued declining over the next 2 weeks from 45 to 24 l/s. This reduction was in line with the predicted capacity of a single NQ drillhole to transmit water to the workings.

REGOLITH AQUIFER POTENTIOMETRIC SURFACE 3

Following the plugging of DRD250 water levels rose rapidly in the Regolith aquifer, and continued to rise at a rate which was linear in relation to logarithm of time. In early January 1999 an unseasonal rainfall event of about 60 mm, which produced runoff and inundation of Lake Zot. Following this event water levels and inflows again rose. Minimal rain was recorded over the next two months and water levels stabilised with inflow rates returning to about 35 l/s.

The cone of drawdown had now shifted to be centred directly over the crown pillar of the upper NO2 ore surface (Figures 2 & 4). The period of reduced inflows (24 l/s) had evidently been transient, while water flowing from the sediments in the east gradually filled the void which was previously drained by DRD250. With a continuous hydraulic gradient from east to west, a steady flow situation was re-established.

Due to the change in the shape of the potentiometric surface, the array of surface piezometers was no longer effective in defining the centre of the cone of drawdown. The zone of leakage from the Regolith Aquifer to the top of the mine was evidently less than 200 m in strike length, but may have been considerably more localised.

UNDERGROUND DRILLING 2

A number of exploratory holes were drilled through the ore surface above the top of the stopes in the NO2 surface and out into the hanging wall, testing a strike length of about 100 m. Dynamic flow tests indicated only moderate permeability and no indication of a hanging wall structure which was continuous long strike. Static pressures were highly variable with a central 40 m long zone of very low pressure.

A further programme of drilling to delineate the zone of groundwater ingress, with a view to evaluating grout sealing options, was being planned at the time that the mine was closed in March 1999.

CLOSURE

In March 1999 the Kambalda region recorded a total of 160 mm rainfall due to the passage of two cyclones in quick succession. This monthly total is among the 5 highest recorded in the region over nearly 100 years of records. This event again raised the water level in both Lakes and reduced the capacity for mine water disposal to Lake Fore. The requirement for further expenditure on water disposal as well as on investigation and remediation at the mine site came at a time when the profitability of all mines was under close scrutiny.

In April 1999, termination of mining at Mariners with nickel resources still in-situ was part of the rationalisation of Kambalda Nickel Operations. While commodity prices and rising production costs were primarily responsible, the cost of ongoing water problems at Mariners was also an important consideration in the closure of the mine.