A Step back in time to Hand-Held Mining for Profitability

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Abstract

The Otter-Juan mine was closed by WMC Resources' Kambalda Nickel Operations (WMC-KNO) in 1999 due to the combined effects of low Nickel prices and high mining costs. GBF Mining Pty Ltd purchased Otter-Juan Mine from WMC in early 2001 as part of WMC's disinvestment from the nickel mines in the Kambalda area. Goldfields Mine Management (GMM), (a wholly owned subsidiary of GBF Pty Ltd) re-opened Otter-Juan in May 2001.

The Otter-Juan mine is one of the oldest mines in the Kambalda region and is now mining at depths below 1160mbs. Stresses are very high, rock mass deformation considerable, and the mine has a history of serious seismic activity. Orebody widths in the current mining area range from 2 to 2.5m, with dips from 25° to 40°.

On taking over the operation, GMM converted the mining method from the previous mechanised drift and fill method to a slot-rise and strip method using hand held airlegs. During the latter years of production under the control of WMC, production averaged around 12000 tonnes per month, with grades of 2.7% and orebody extraction of only 55 to 60%.

In the last three years of operation under the control of GMM the mine has produced an average of 12000 tonnes per month of ore at an average grade of 4.2% and with an orebody extraction of 70 to 75%. The mine is now highly profitable with at least another 3 years of reserves remaining at depth. The main benefits of the current method include reduced dilution and increased extraction. In the relatively poor ground conditions experienced this has only been possible using airleg mining, with excavations designed to suit conditions, support to suit rockmass deformations, and with improved extraction sequencing.

Other benefits have included improved operating conditions, reduced falls of ground incidents and a dramatic reduction in seismic activity. These achievements have only been possible by stepping back in time and using traditional airleg stoping methods to extract the maximum amount of the orebody with minimum dilution. This paper includes details of the mine history, geology, mining method, seismicity, and support.

Introduction

Airleg mining in Australia has been on the decline over at least the past 10 years. This has been partly due to tonnage productivity benefits of electric-hydraulic jumbos and longhole production drills and partly due to safety initiatives by State Mining Inspectorate Departments and larger mining companies (e.g. WMC). At many of the mines operated by the large mining companies there are no longer any miners using airleg machines due to the fact that the use of them has been limited by self-regulation and the move to higher productivity and non-entry methods, particularly with the trend towards contract mining.

A result of this has been increased ore drive and stoping dimensions to suit equipment instead of orebody width. This in turn has led to increased mining costs per tonne of ore and inevitably some orebodies have become uneconomic due to such mechanisation.

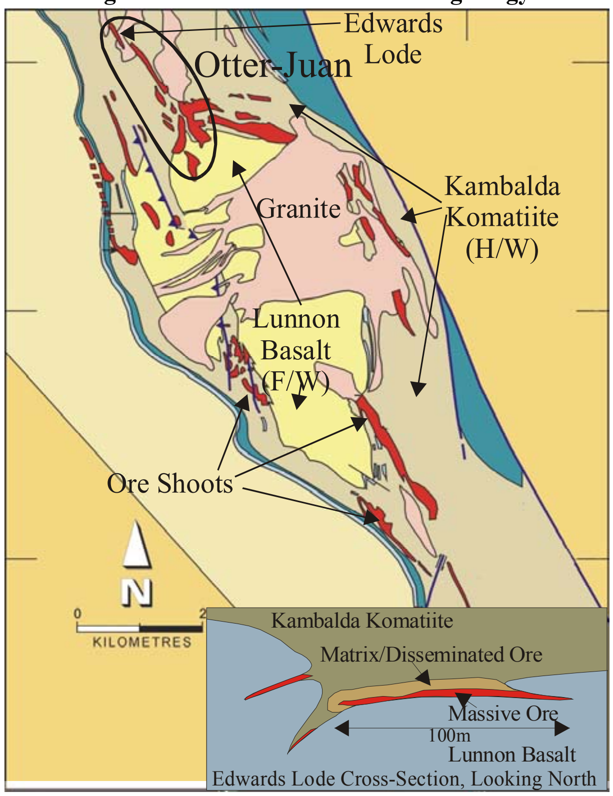
Geology

The Otter-Juan mine encompasses over 60 ore shoots and is located on the northwest boundary of the Kambalda Dome (Figure 1). The ore shoots at Otter-Juan are hosted in the Kambalda Komatiite Formation, immediately in contact with, or contained within the underlying basalt (Lunnon Formation) (Gresham and Loftus-Hills, 1981). The Lunnon Formation is a tholeiitic basalt varying from massive to pillowed and generally very competent.
Typically in the centre of the main Edwards (62) ore shoot there is a layer of massive ore (80-100% sulphides,10 to 17% Ni) (Heath et al 2001) immediately above the basalt with a thickness of around 0.8m. Above the massive ore is a 1.2 metre thick layer of matrix ore (40-80% sulphides, 2.5 to 7% Ni) and overlying this unit is a

disseminated ore (10-40% sulphides, 0.5% to 2.5% Ni) layer up to 0.5 metres in thickness. The hangingwall to the ore profile is a talc–magnesite–chlorite ultramafic rock unit, which along with the disseminated ore tends to deform and exhibit 'creep' under the high-stress conditions experienced in the lower sections of Otter-Juan.

The average strike direction of the Edwards ore shoot is east west, the average dip is 25° toward 300° and the average strike length is 150 metres.

Figure 1 Kambalda Dome geology



Mine History

Since 1966 the Kambalda dome has produced over 25.7 million tonnes of ore at an average grade of 3.24% nickel from 10 separate mines (updated from Banasik, 2003). The Otter-Juan ore shoot was mined by WMC Resources (WMC) from 1968 to 1999, when it was placed on care and maintenance. A number of other mines in the Kambalda region were similarly placed on care and maintenance by WMC from 1998 to 2001. The WMC Kambalda Nickel Concentrator maintained a reduced level of production throughout this period. In May 2001 the mine was sub-leased to Goldfields Mine Management Pty Ltd (GMM), who immediately recommenced production.

Cumulative production from the mine is by a long way the highest in the region, at over 7.85Mt and at an average grade of 3.54%Ni for a contained nickel metal total of over 277,000 tonnes (updated from Banasik, 2003). Currently the majority of production is sourced from the Edwards ore shoot, which is the deepest and most northerly ore shoot at Otter-Juan, and is also the most northerly known orebody on the Kambalda Dome.

Mining Methods

Historically the mine commenced production in the late 1960s using airleg stoping methods. These methods continued through to the mid-1990's when more use was made of mechanisation such as jumbos and loaders. In the late 1990s the mine had converted to a drift and fill method for the Edwards Lode. This method was being undertaken using single boom jumbos, with minimum drift heights of around 3.3m. A few critical issues were apparent with this method:

- the minimum mining width was significantly wider than the orebody
- the drift height was insufficient to enable effective bolting (bolts generally installed at shallow angles)
- the fill could only be placed by loaders and even with the addition of cementitious products was not able to provide support to the backs, loss of blasted ore on top of the fill or prevent fill being loaded out with the broken ore.

- ground conditions deteriorated as extraction continued per panel, inevitably becoming unmineable and resulting in loss of reserves
- overall extraction of only 65%

GMM purchased the mine and re-commenced production in May 2001 following due diligence studies on the overall economics and in particular, studies to improve the mining method used at the time of closure. GMM chose to use airleg miners and a slot rising method (rising and pillar stripping) to minimise dilution and this method continues to the present date with extraction percentages averaging 75%.

The method involves accessing the orebody from a footwall decline, developing ore drives and then using airlegs to mine the orebody using a rise and strip, room and pillar type method. The mining sequence is illustrated in Figure 2. The high stress environment with associated high deformation rates and an inherent risk of seismicity, require that the extraction sequence follows a top-down approach with stoping retreating to a solid abutment. The stope extraction design results in pillars yielding as soon as they are cut, and the stope support system copes well with the associated high levels of deformation. This has the benefit of re-distributing stresses over a wide area and removes the peak pillar loads that historically led to seismicity and pillar bursting. The basic excavation dimensions and equipment involved in this method are summarised in Table 1.

Figure 2 Mining extraction sequence

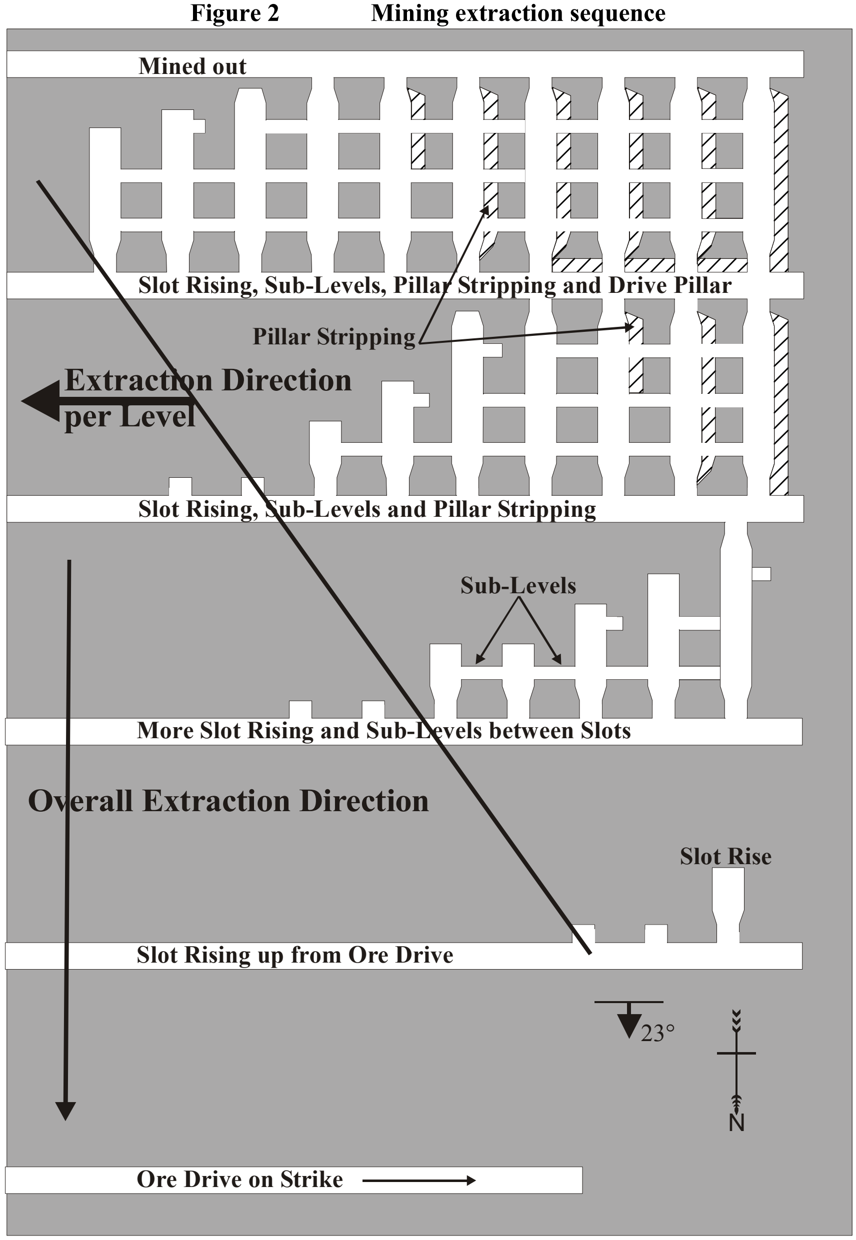


TABLE 1 Mining dimensions and equipment

Excavation	Size (W x H)	Rock Type	Equipment	Comments
Decline (1:7)	5 x 5.5m	Basalt	2-boom Tamrock D07 Axera R2800 Elphinstone loader Toro40D and 50D trucks	25m stand-off distance below orebody
Return air drive	5 x 5m	Basalt	“ “	25m sub-level intervals
Return air rise	5 x 5 m	Basalt	Tamrock Solomatic 720 R1700 Elphinstone loader	61R raisebore used for 1.2m slot
Access drive	4 x 4.5m	Basalt	“ “	Targets Eastern edge
Ore drive	3.5 x 3.5m	Basalt, orebody & ultramafic	Single-boom Tamrock Monomatic and Quasar jumbos R1500 Elphinstone loader	Driven on strike, East to West. 12m sub-level interval
Orebody Slot Rises	3 x 2.5m	Orebody	Boarmax and Atlas Copco Panther rockdrills, SIG airlegs and electric scrapers	3m wide, 4.5m pillar between slot rises
Orebody sub-level drives	2 x 2m	Orebody	“ “	2m wide, 6m up-dip pillar between drives
Pillar stripping	1.5m wide	Orebody	“ “	1.5m stripping of pillars

Mining Costs

Mining costs per **tonne** at Otter-Juan are currently higher than previous cost levels, due to the combination of reduced productivity levels of airleg miners and high labour costs. 1995/6 costs for WMC have been escalated at 3% per year to compare with current 2003/4 GMM costs. The cost per tonne for WMC was $141 per tonne and for GMM $165. This cost includes all mining related costs such as stoping, development, haulage, administration, management and equipment maintenance, but not including treatment or finance charges.

The cost per **pound** of nickel has been greatly reduced however (Table 2) from $2.35 to $1.75 due to the increase in grade from the selectivity of the current mining method, and the mine has changed from being marginal to being highly profitable. In line with this reduced production cost has also been in increase in extraction percentages, from around 65% up to 75%.

TABLE 2 Comparative costs – mechanised (WMC) and airleg (GMM)

	WMC (1995/6)	GMM (2003/2004)
Tonnes Delivered	141,884	172,131
Grade	**2.73% Ni**	**4.31% Ni**
Contained Ni Metal	3,872	7,427
Mining Cost per Tonne Ore	Aus$**141** *	Aus$**167**
Mining Cost per Contained Ni lb	Aus$**2.35** *	Aus$**1.75**
Manpower Total	80	85
Capital Dev. cost/m	Aus$3,650 *	$2,940
Access Dev. cost/m	Aus$1,920 *	$2,168
Production Cost/ tonne Ore	Aus$69 *	$61
Admin/Mine Services cost/t Ore	Aus$5 *	$6

* Escalated from 1995/6 to 2004 @ 3%pa

Whilst the GMM unit costs per pound of nickel are lower than WMC, the total cost per tonne is higher due to the fact that the GMM design requires more development metres per tonne of ore than WMC required. The production cost per tonne includes all stoping related costs plus costs for strike driving on ore. The capital development cost reduction has been achieved due to a decrease in decline dimensions.

Stress and Rock Strength

In-situ stresses were measured on 31 Level, at 980mbs using CSIRO Hollow Inclusion Cells (AMC, 1998). The Major and Minor Principal stresses were measured at 68.6 and 35.5MPa respectively. This high level of stress is typical of the Kambalda-Kalgoorlie area and some other areas in the Yilgarn Block in Western Australia (Lee, Pascoe and Mikula, 2001). Assuming this rate of stress increase continues with depth (7MPa per 100m), the virgin stress levels at the current lowest operational depth of 1200mbs are over 80MPa and at 1400mbs will be around 100MPa. There are no indications that the current mining method and support systems will not be successful at such stresses. Rock property results from intact tests are shown in Table 3. The results highlight the reason for the high deformation rates – the low strength of the ultramafic in the hangingwall and disseminated ore relative to very high stresses.

TABLE 3 Intact rock property summary

Rock Type	UCS (MPa)	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)
Massive Sulphide	140	51	0.12	4.85
Basalt	275	80	0.22	2.96
Ultramafic	76	53	0.36	2.90

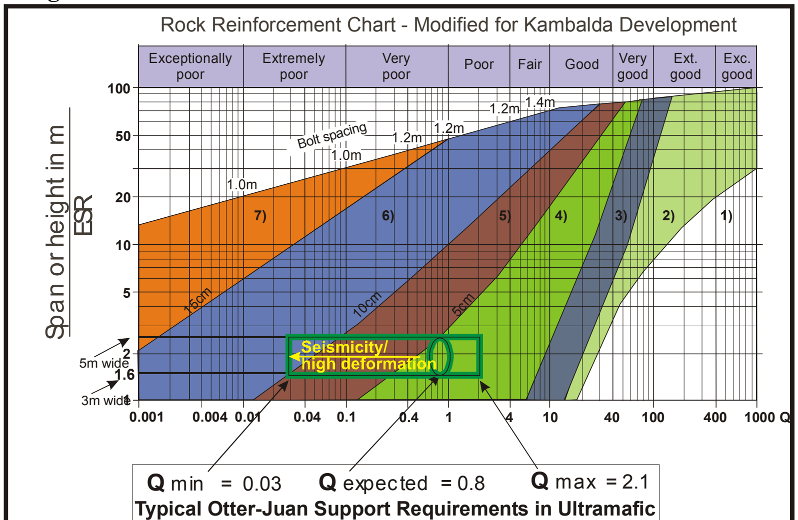
Support Systems

Essentially there are three support and reinforcement regimes used at Otter-Juan:

- Mesh and SS46 Split Sets in the decline and footwall access development (in basalt)
- Mesh and SS46 Split Sets and additional 20mm Threadbar Bolts in predominantly ultramafic ore drives
- Mesh and 20mm Threadbar Bolts in stopes

These systems have been developed through performance and experience on site and are well suited to the installation equipment and to the rockmass deformations. All mesh and all split sets are galvanised to minimise the detrimental effects of corrosion (very high salinity groundwater). The Rock Quality Q and support systems used at Otter-Juan do not conform to the support categories in the Rock Reinforcement Chart (Grimstad and Barton, 1993) therefore a Kambalda specific version of the chart was produced (Figure 3).

Figure 3 Modified rock reinforcement chart to suit Kambalda



SUPPORT CATEGORIES

1) Unsupported
2) Spot bolting (eg split sets)
3) Systematic bolting(eg split sets)
4) Systematic bolting(eg split sets) and mesh
5) Systematic bolting (eg Threadbar) and mesh or 5-10cm fibrecrete, bolting and mesh
6) 10-15cm fibrecrete, mesh and bolting (eg Threadbar or Cone bolts)
7) >15cm fibrecrete, reinforced ribs of shotcrete and bolting (eg Threadbar or Cone bolts)

Decline and access development in basalt

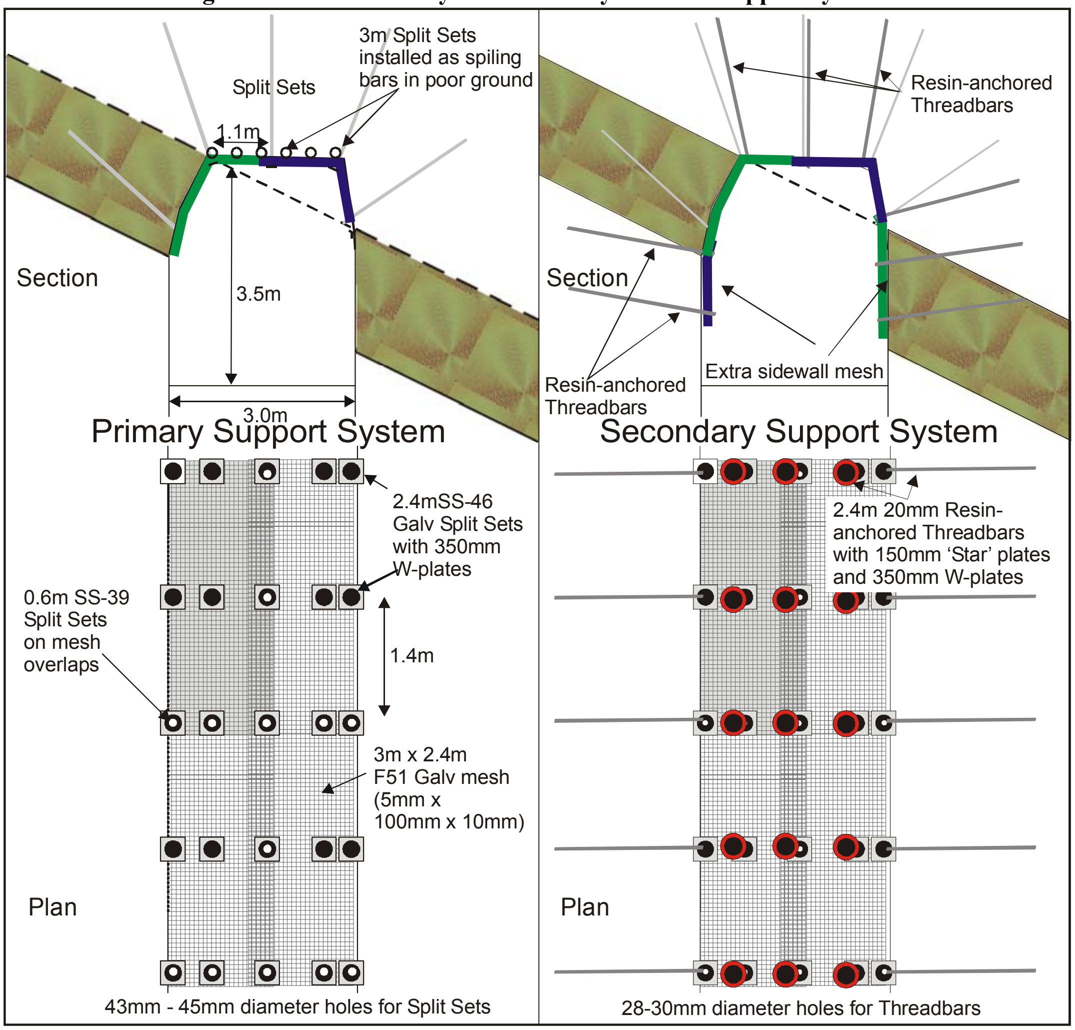
The support and reinforcement scheme in basalt development involves comprises F51 weldmesh and galvanised SS46 split sets. Mesh sheets are 2.4 x 3 or 4m in size, with 5.6mm (galvanised) wire strands and 100mm x 100mm apertures. 2.4m, 46mm split sets are installed in 43 to 45mm diameter holes. Bolts are plated with dragonfly plates consisting of a domed plate welded onto a butterfly plate. SS39 split sets are installed within the larger split sets in order to overlap the mesh sheets. Bolts are spaced on a 1.1 x 1.4m pattern, to suit the mesh, with a ring spacing of 1.1m.

Additional cablebolt reinforcement is installed where required usually at major intersections or where structural wedges have been identified (twin-strand 15.2mm, cables with bulbs and 6m to 9m long). Sheets of mesh are also occasionally bolted to the face in when rocknoise and minor strainbursting are experienced.

Ore Drive Development

Support and reinforcement of oredrives is essentially a two-pass scheme (Figure 4). The first pass involves installation of F51 mesh and SS46 split sets by a single boom jumbo as described above. Spiling bolts are used in ore drives at the operators' discretion to assist in stabilising the backs. The spiling bolts are 3m long, 46mm diameter split sets (without washers/plates), which are installed on a 0.5m spacing angled up at about 10° above the horizontal. Spiling bars have proven very successful in stabilising very poor talc-chlorite shear zones.

Figure 4 Primary and secondary ore drive support systems



Upon completion of the drive 20mm (black) Threadbar bolts, 2.4m in length are installed with an airleg machine, using 2.2m long and 28-30mm diameter holes, and a single 20mm x 600mm medium set resin cartridge. Threadbar bolts are plated with a 150mm x 5mm star plate welded to a 350mm butterfly plate (black) (plain dome plates were found to fail due to the high rockmass deformation). The yield strength of the Threadbar bolts is approximately 500MPa with an elongation capacity of the order of 16 to 19%.

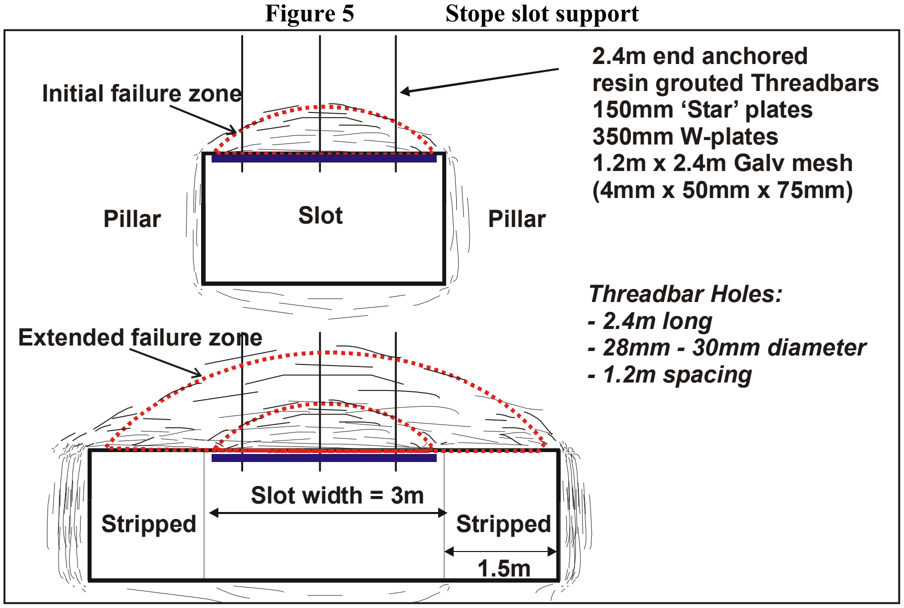
The idea behind the two-pass reinforcement system is to allow the drive to yield prior to the second phase of reinforcement being installed, thereby increasing the life of the Threadbar bolts as the ultramafic rock squeezes. The use of mild-strength steel Threadbar bolts allows stretch of up to 300mm. The Threadbars have also proven very capable of coping with minor rockbursts.

Stope Development

A single-pass support and reinforcement scheme is used in slot (stope) development and comprises 4mm weld mesh and 20mm resin-encapsulated Threadbar bolts installed using an airleg machine (Figure 5). Bolt lengths are usually 2.4m, however where the slot height has been reduced for dilution control or due to poor ground conditions, 1.8m bolts are used because of sufficient room to install longer bolts, at an effective angle.

The mesh used in the slots is a lighter grade than in jumbo development and the sheets are smaller to facilitate easier installation by the miners. The (ES45075) weldmesh is galvanised, with 4mm strands, 50mm x 75mm apertures and 1.2m by 2.4m sheets, with a weight per sheet of 10.2kg. The resin used for Threadbar installation is Fosroc (Minerva) medium set, 600 x 20mm. The Threadbars were initially supplied with locknuts that remained intact during the resin mixing using the airleg drills, but sheared once the resin set. This has now been replaced by a threaded insert for the airleg drill chucks, which can spin the bolts without the use of nuts. Installation of nuts and plates and tensioning of the bolts is undertaken using air-powered impact wrenches.

Figure 5 Stope slot support



Seismicity

There have been reports of mining induced seismicity at Otter-Juan since the 1980s. This has mainly been due to the effects of increasing stresses (virgin plus mining component) on stiff (e.g. massive sulphide) pillars – especially with critical dimensions between 4m and 6m.

An ESG microseismic monitoring system was installed in 1998 by WMC at Otter-Juan mine. The system currently comprises an array of 11 uniaxial accelerometers and 4 triaxial accelerometers. In WMC's final production year (1999), typically 40 events per day were being detected (Turner, 2001). In general the rate of seismic activity at Otter-Juan mine has been relatively quiet since re-opening in May 2001. Since November 2003 an average of between 3 and 4 events have occurred per day with the number of events ranging from 0 and 38 per day. Much of this activity has been associated with a porphyry intrusive which transects the relatively soft ultramafic host rocks. Movement along the margin of the porphyry and small rockbursts have been observed. Rocknoise report cards are filled in by miners to assist in correlating noise with events monitored by the seismic system. The reduction in seismic activity since GMM commenced mining activities can be attributed to a number of factors:

- a reduction in the size of the hangingwall span exposed in stopes
- a change from central access to footwall access at one end of the orebody
- a sequential mining sequence
- reduced exposures of hangingwall basalt
- the use of yielding pillars.

Increased mining depths with associated stress increases are generally expected to lead to increased levels of seismic activity around development and stoping excavations and along contacts between stiff porphyry intrusives and the weak ultramafic hangingwall rockmass.

Safety

In Australia as in other countries there has been a drive to zero tolerance regarding accidents. Some of the major companies have approached this by adopting non-entry mining methods that do not expose any personnel to the stoping face that inevitably means using mechanised mining methods. This approach has been chosen rather than developing procedures and mining dimensions for entry stoping methods that mitigate the risks to personnel. The airleg mining method at Otter-Juan is designed with strict controls on mining dimensions, access and extraction sequence, which combined with effective excavation and support designs incorporating surface support in the form of mesh allowing work to be carried out under secured ground minimizes the exposure of personnel to rockfalls.

Conclusions

The use of an airleg-based stoping method for extraction of narrow orebodies at depth at Otter-Juan in high stress and poor ground conditions has proven to be very successful and has resulted in:

- A significant reduction in stope dilution
- A greatly reduced cost per pound of Nickel
- Reduced seismicity as a result the reduction in size of hangingwall spans and a sequential mining sequence

The higher-grades resulting from the return to an airleg based mining method have greatly increased the profitability of the mine and will enable it to continue mining for at least another 4 years and to depths of 1400mbs.

The use of a support system based on mesh with deformable bolts and the use of yielding pillars has also combined to limit seismicity and allow mining to continue in high stress conditions in a weak, highly deformable rockmass.

The authors would like to thank the technical staff at Otter-Juan for providing data, and also to thank the miners for accepting, without too many complaints, changes to support systems and designs.

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