# Ground control at Leinster Nickel Operations

by J. Cahill* and M. Lee*

## Synopsis

**Leinster Nickel Operations, located in Western Australia, consists of an underground and three open pit mines in relatively adverse ground conditions. This paper reviews our ground control practices in the open pits, covering aspects of ground support, wall control and monitoring. These methods have been effective in allowing mining operations to continue beneath unstable slopes. In particular, the use of Groundprobe's slope stability radar has enabled the Harmony open pit to safely operate for months following indication of failure from traditional methods. This case study highlights the benefits of investing in appropriate slope stability monitoring systems.**

## Introduction

BHP Billiton's Leinster Nickel Operation (LNO) is located 600 km north-east of Perth in the Eastern Goldfields Region of Western Australia (Figure 1). The LNO deposits (known as Perserverance, Rocky's Reward, Harmony and 11 Mile Well ) are situated within the Wiluna Greenstone Belt and the orebodies are hosted in Komatite Ultramafic lava flows (Figure 2).

The Perserverance orebody has been mined at surface by open cut and extends underground to a current depth of 1 100 m. The Perserverance underground mine is the only mine currently in operation at Leinster. The main orebody is mined by sub-level caving. Surface operations consist of monitoring the subsidence caused by the underground operation, on the completed open pit and surrounding infrastructure. A programme is currently underway to backfill a portion of the pit with waste material, to slow the rate of subsidence and minimize the effects on nearby ventilation and haulage shafts.

The Rocky's Reward orebody has been mined by open cut and underground stoping methods. A recent scavenge operation, extracting a portion of the crown pillar was completed in June 2005. A planned cutback is currently under review and due to start mining mid-2006.

Harmony commenced mining in March 2000. The pit was mined in three stages and included cutbacks due to wall failures. A comprehensive ground control management plan was developed in order to manage the risks associated with further wall instability, particularly in the final 12 months of operation up until closure in August 2005.

The 11 Mile Well orebody was mined by open cut methods and was completed in September 2005. Although a small operation (18 month project), localized instability of the walls necessitated a redesign after 6 months. Monitoring techniques developed at Harmony were used to safely complete the pit.

This paper introduces the ground control management process that is implemented at all Leinster Nickel Operations' open mines. It then presents case histories of wall failures at the Harmony pit and Section 4 shows how the learnings from previous failures refined the hazard management process.

## Ground control and hazard mangement

This section details how geotechnical hazards are managed at Leinster Nickel Operations' open cut mines.

The object of ground control is to provide a safe and efficient mining operation.

Minimization of the adverse effects of slope instability can be accomplished through sound mine planning and the establishment of operational procedures.

The key elements of ground control at Leinster Nickel Operations are:

- ➤ identification and assessment of structural features
- ➤ geotechnical input into slope design
- ➤ blasting control and batter clean-up

---

* *BHP Billiton, Leinster Nickel Operations.*

© *The South African Institute of Mining and Metallurgy, 2006. SA ISSN 0038–223X/3.00 + 0.00. This paper was first published at the SAIMM International Symposium,* Stability of rock slopes in open pit mining and civil engineering situations, *3–6 April 2006.*

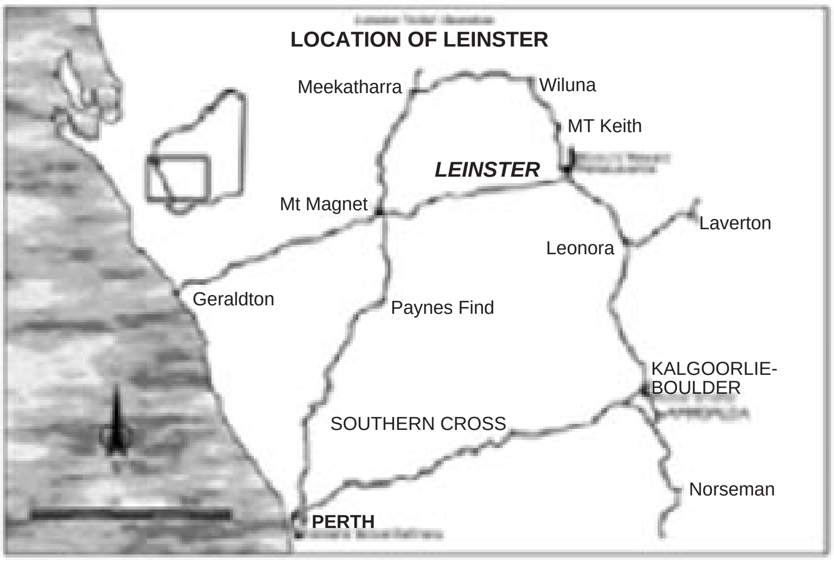

**Figure 1—Location map of Leinster, Western Australia**

**Figure 2—Regional geology of the area surrounding Leinster**

- slope monitoring
- ground support
- slope assessment training for all personnel.

In the case of the Harmony open pit, slope monitoring and ground support were used extensively to enable operations to continue for 6 months after prediction of major wall failure.

### Structural mapping/pit design

Structural mapping and interpretation were undertaken on a regular basis, to assess and predict wall movement. The geomechanics team worked closely with mine planning, to ensure a pit design that minimized the effects of existing rock mass conditions. Structural mapping was also used in the determination of ground support requirements.

### Blasting control and batter clean-up

All blasts were observed by a geomechanics engineer and video recorded for further analysis. The geomechanics engineer accompanied the shot firer to clear the shot, undertaking an immediate pit wall inspection prior to reopening the pit. Remote firing devices were used in order to reduce the risk of personnel in the pit being exposed to blasting related instability.

Figure 3 shows the increased rate of movement following blasting. Accelerated movement was monitored until a steady rate was established prior to blast clearance.

Batter face scaling and washing were incorporated in the mining process to ensure that all loose material was removed, reducing the risk of small rock failures in the later stages of the pit life.

### Slope monitoring

Slope monitoring involves different techniques, each one providing important information to the overall success of the operation.

#### *Visual inspections/crack monitoring*

Visual inspections were carried out by the geomechanics engineer at the beginning of shift, immediately following any blast, and as required. Gauges were installed to monitor any observed cracks. In critical areas, a data logger was used to continuously record data, with a movement alarm attached and scanning crack gauge dilation every 60 records.

#### *Prism monitoring*

There were over 400 prisms in place in the Harmony pit, each linked to an automated Leica system. The system was controlled by Softrock Solutions Autoslope software and the data was viewed using Quickslope. The prism movements were checked daily by both the surveyors and geotechnical

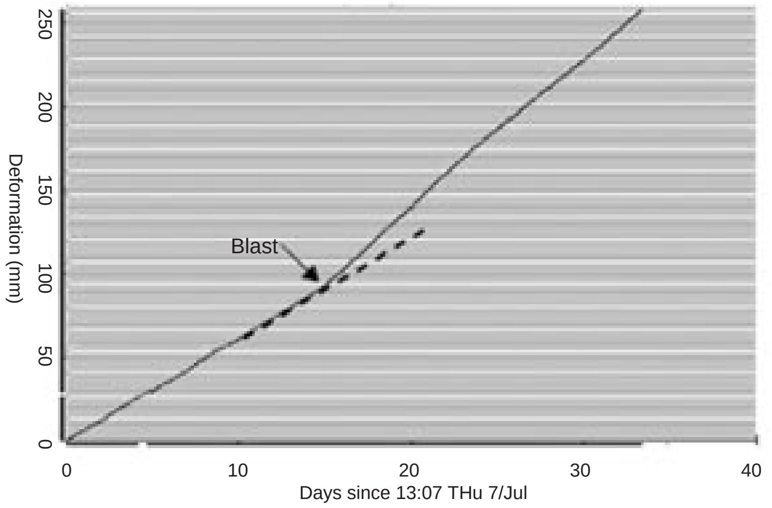

**Figure 3—Accelerated wall movement due to blasting**

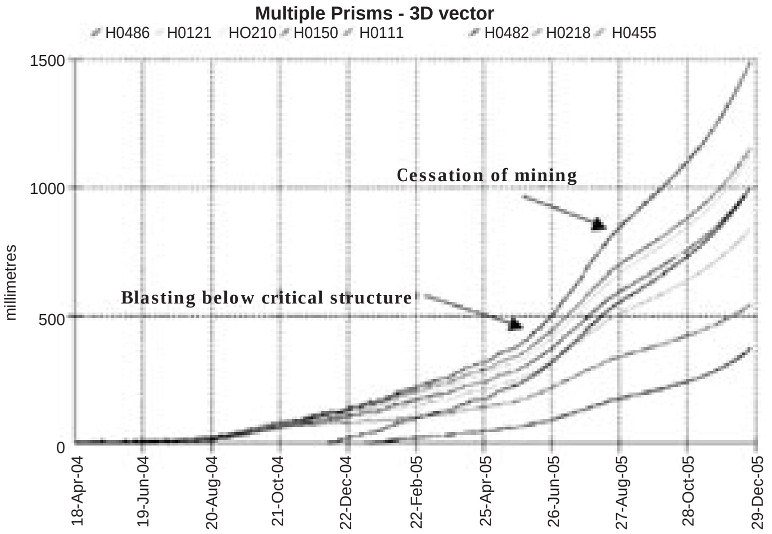

**Figure 4—Prism movement data represented in Quikslope's graphing tool**

engineers. Alarms are set for each prism at tolerance levels marginally higher than current movement rates to advise of acceleration. The alarm consisted of an audible noise at the computer in the monitoring office and e-mails forwarded to relevant personnel. SMS alarming was also available.

The continuity of the prism data allowed for the long-term assessment of wall movements. The geo-referenced nature of the data allowed it to be used for assessing vector movements of the pit walls and failure mechanism determination.

Figure 4 shows typical prism movement in the south-east corner, where readings were taken every 24 hours. Prism rates accelerated after blasting below the critical structure. Rates decreased for a short time following cessation of mining, but continued to increase in the long-term.

### *Slope stability radar*

Groundprobe's slope stability radar (Figure 5) has been in use since 2002 at Leinster. The radar continuously monitored the wall and was focused on areas where there was a low confidence level on the ability of prisms and visual inspections to predict failure with adequate time to remove all personnel and equipment. Scan times were generally 10–15 minutes, with the data being sent via radio link to the monitoring office. Audible alarm tolerance settings were based on previous failures in similar ground conditions.

The radar often showed higher velocities of movement to that of prisms. This is due to two reasons. Prism data are point data only and therefore higher movement may be recorded between prisms by the radar. Alternatively, the radar scans the surface of the wall, as opposed to prisms, which may be placed to record slower deep-seated movement.

Occasionally lower velocities were recorded by the radar. This can be due to the angle of movement relative to the radar producing a lower two-dimensional magnitude, whereas prism movement is recorded three dimensionally. The combination of both radar data for monitoring potential failure near the face, and also prism data for modelling deep-seated failure mechanisms were essential for efficient Leinster operations.

Figure 5—Groundprobe's slope stability radar, monitoring the south east wall at Harmony

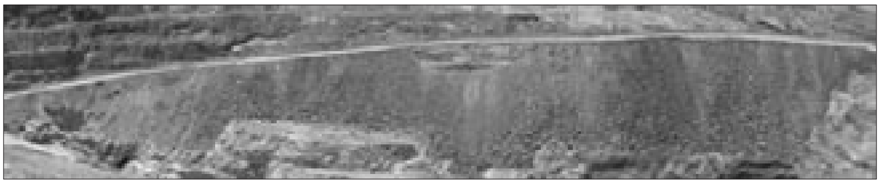

Figure 6—Rock fill buttress placed to increase stability of the main haulage ramp

### Ground support

Ground support was installed in the open pits on the following basis:

- Cable bolts in crest of single lane ramps
- Mesh or catch fences in areas where small failures cannot be prevented by wall control or predicted by monitoring
- As required, determined from structural mapping analysis.

Ground control was also implemented by using backfill to buttress against unstable sections of wall (Figure 6). Fill buttressing was proven effective in stabilising a major ramp, where relative movement within the ramp was halted.

### Personnel awareness

A major part of hazard management is crew awareness. Before any personnel were allowed to work in the pit they had to complete a geomechanics induction.

This induction highlighted the current knowledge of wall movement and the expected mode of occurrence for further failure. The monitoring systems were shown in detail, including case studies of how previous failures had been detected.

Geotechnical hazard maps were produced and displayed in common areas as an easy reference to crew members of the slope hazards that existed in the pit. These maps showed previous failure zones, prism movement rates, radar scan areas and high potential rock fall areas. Hazard maps were updated on a monthly basis.

All crew members were updated with weekly plots of the prisms' movement velocities and relevant radar monitoring data. Following closure of the pit due to wall movement, rainfall or false alarms, the crews were briefed prior to re-entry into the pit. Updated information posters showing wall movements, changes to alarm thresholds and changes of evacuation procedures were presented and displayed in common areas.

The inclusion of all the key elements discussed above in the ground control management process leads to confidence in dealing with adverse ground conditions.

## Wall failures

This section presents some case studies on wall failures that occurred at the Harmony open cut. Data from each failure were collected and analysed, leading to greater confidence in working under unstable slopes.

### Komatsu ramp failure

A major failure to occur in the Harmony pit was that of the Komatsu Ramp on 8 October 2002.

The structurally controlled failure occurred in weathered material and was predicted by prisms and crack gauges, giving adequate warning to remove the crew from the pit.

### 1C slip

The 1C slip was an extension to a previous failure. It occurred on 23 June 2003 while a clean-up was being undertaken to reestablish mining in the area following the initial failure.

The failure was anticipated from 18 June due to movement observed in prisms and crack gauges. Figure 9 shows the crack gauge data, with distinct acceleration of movement.

Montoring of area continued by radar, which showed significant acceleration approximately 12 hours prior to failure (Figure 10).

**Figure 7—The Komatsu ramp failure, Harmony open pit**

**Figure 8—Harmony 1C slip, showing existing failure to the right, with extension outlined**

Monitoring of this failure gave confidence that prisms and crack gauges would give adequate warning of impending failure in similar ground conditions. Furthermore, the radar monitoring showed that once the prisms and crack gauges indicated failure, there was still a significant amount of lead time prior to the onset of wall failure. This data clearly showed the benefits of radar monitoring, when working under unstable walls.

### North-east wall fresh rock failure

The north-east wall fresh rock failure occurred as an extension of a previous failure. Due to the recognized potential for further instability, the radar was used to monitor the area while work was occurring nearby. The prism system was inoperative, since no new prisms could be installed on the batter face. The radar detected movement prior to slab failure then movement continued until a second slab failed approximately two days later.

Figure 11 shows wall data as seen on the radar screen. The plot bottom right is a heat map of wall movement over the section in the photo top right. The two figures on the left show movement over time for selected areas of the wall.

The monitoring of this failure gave confidence in the radar's ability to give forewarning for failures that occur in hard rock. Initial failure occurred within a period less that the average time between prism readings. It also demonstrated the ability to determine if further failure was likely to occur.

### South-east corner slab failure

Although only a small failure, the south-east corner slab failure had major repercussions. As it fell, the slab broke apart and a small rock hit a geologist in the leg. A minor injury was sustained, and the incident was classified as an serious potential incident (SPI). The area of failure had not been showing any excessive movement, and the slab that fell was too small to be picked up by any of the monitoring systems, including radar. The pit was closed, pending assurance that the incident could not be repeated.

Extensive knowledge was gained from previous experience and data of wall failure at Harmony. Each failure enabled refinement of the monitoring procedures and provided confidence in the ability to predict future failure.

## Harmony open pit scavenge operations

This section details how the ground control management process and experience gained from previous failures were used in mining the southern most portion of the Harmony open cut.

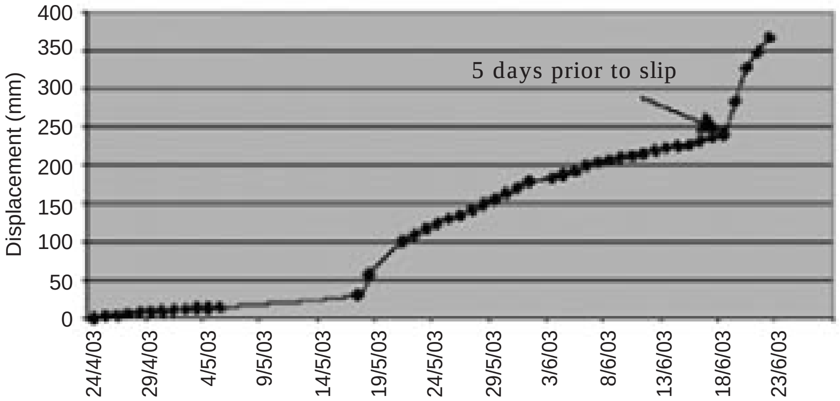

Figure 9—Crack gauge data from the 1C slip

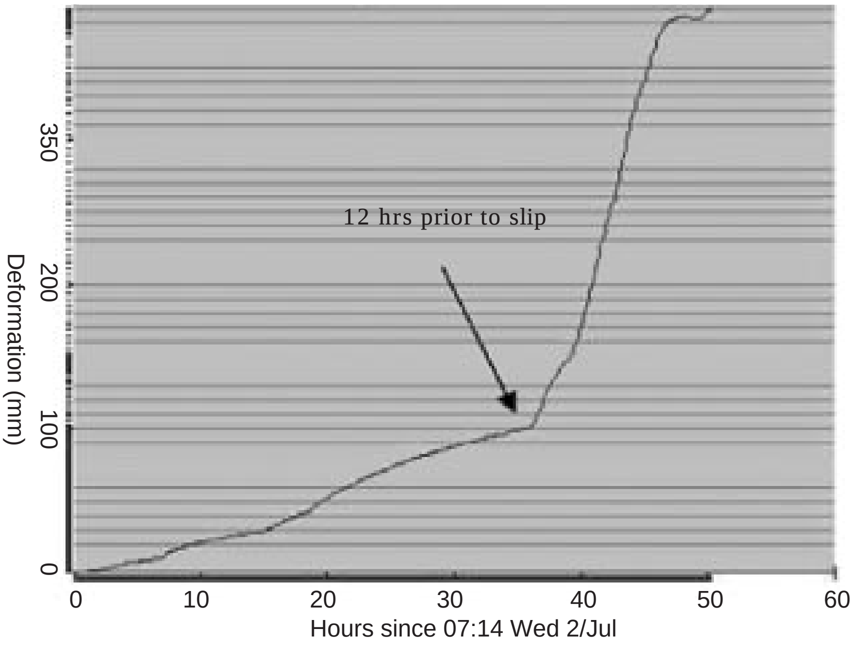

Figure 10—Radar data of the IC slip extension failure

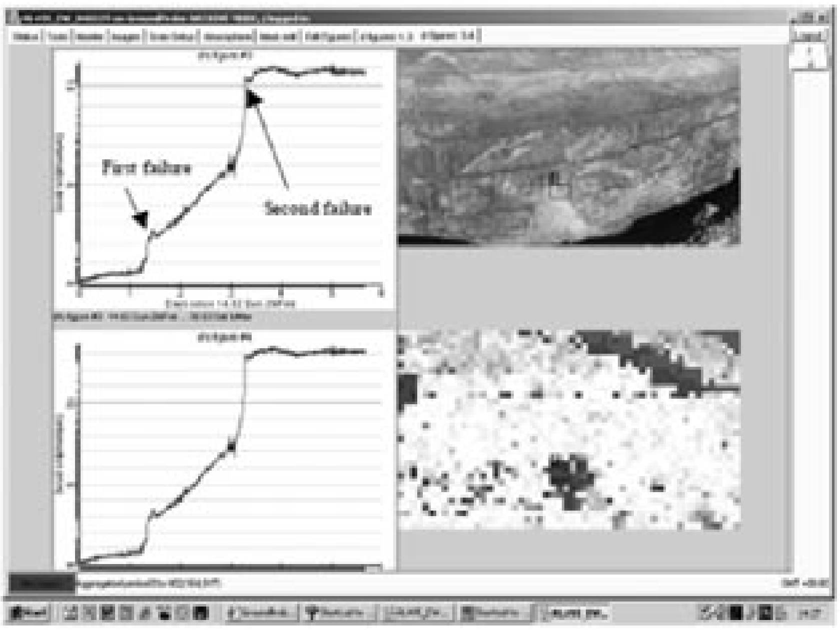

Figure 11—Radar data of two slab failures in fresh rock

The Harmony South Park Scavenge operations had many challenges to overcome. In order to begin the final stage, the geomechanics team had to solve the issue of small slab failures, and also large-scale movement accelerating in the south-east corner.

### Mining overview

The mining crew were brought in on an hourly hire contract, as opposed to volume based, to counteract the timing difficulties associated with working in such a small area and delays while installing ground support.

The mining plan for the South Park Scavenge was to use the waste to create a fill ramp to access the ore. This fill ramp would also further buttress the east ramp that had experienced instability during previous mining. This ramp would progress down the east ramp as South Park was mined down, with cuts taken as the South Park floor was mined out.

The crest of the fill ramp experienced minor slumping along the edge during a rain event and commonly at the active tip heads, these areas were dozed over and the tip head reestablished. It was not practical to use the radar on the fill ramp as the movement rates were too great as the fill ramp settled and compacted.

Figures 12 through 14 show the progression of the constructing, and then excavating the fill ramp. Figure 12 shows waste rock being placed to access upper benches. Placement of the fill temporarily slowed wall movement rates. Figure 13 shows excavation a further 30 m in depth. All geotechnical analysis to date indicated major wall failure if mining continues past this point. The final pit, a further 43 m past.

### Ground support

In order to reduce the risk of slab failure, ground support was installed in the fresh rock areas. A full face height rock-link curtain was installed from the base of oxidation and consisted of 20 and 30 m rolls that were pinned on a berm. These were then stitched together, with more rolls added as the floor was mined out. The final rock curtain was 250 m in length and 90 m in height.

Cable bolts were installed along the crest of every berm and catch fences were installed in areas where access had prevented the installation of a curtain. During mining there were several failures that occurred behind the mesh curtain and fences that were fully contained. Figure 15 shows a newly constructed fence, with the start of a curtain begun below the fence.

### Pit wall monitoring

The accelerated movement in south-east corner was managed in a similar manner to the previous large failures in weathered material. Cracks existed down the pit wall 50 metres from the surface to just above the ramp, which was the only means of egress.

Tension cracks on the surface ran parallel to the strike of the bedding of the felsic material that makes up the upper east wall. These cracks extended up to 70 metres behind the pit crest. The base of the movement was believed to be one of set of major west dipping structures that would be exposed during the mining of South Park.

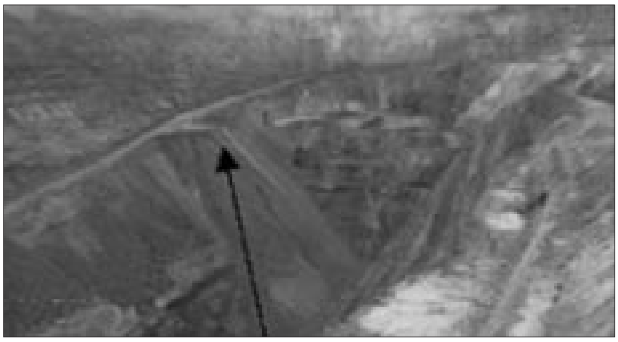

Figure 12—Construction of the fill ramp

Figure 13—Excavation has advanced 30 m in depth

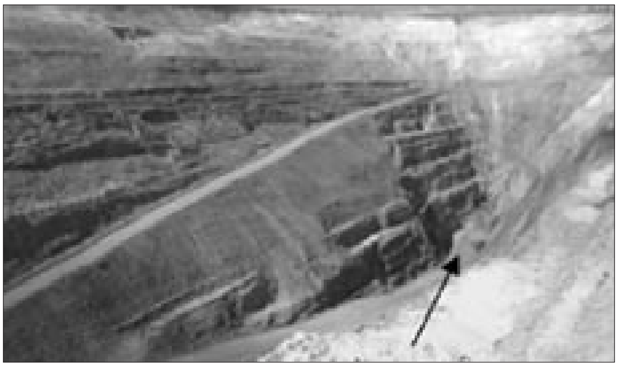

Figure 14—The final result a further 43 m in depth

Figure 15—Catch fence and mash curtain

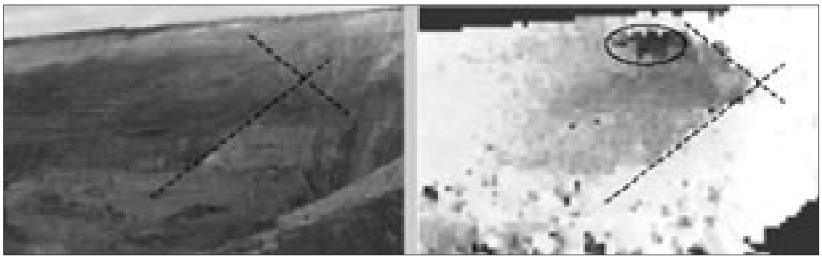

Figure 16—Radar data of south east wall

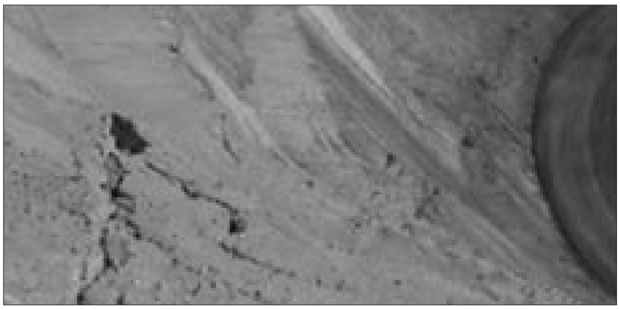

Figure 17—Cracking and slumping of a berm above the ramp

Figure 18—Post failure

The ATS prism monitoring system, crack gauges and visual inspections had indicated movement in the SE corner of the pit since 2002. This was confirmed by the radar with data showing strong correlation. At the beginning of the South Park scavenge the overall wall movement was approx 1 mm per day. When mining ceased rates were up around 6 mm per day.

In the later stages of mining there were movements of up to 20 mm per day recorded on the batter faces by the radar, indicating that they were starting to buckle. Figure 16 shows radar data of the south-east wall. The structural boundaries of the movement are clearly visible on the movement heat map on the right. Circled in Figure 16 and photographed in Figure 17 is the uppermost berm, which showed extensive cracking and slumping.

### *Pit closure*

At 01:30 am on the morning of 14 August 2005, the mining crew was evacuated to the in-pit muster point due to the occurrence of a radar movement alarm. The geomechanics engineer on site was called out and after reviewing the radar and prism data and inspecting the ramp; the crew were evacuated from the pit and sent home for the rest of the shift.

Over the following days the pit remained closed as the area that had alarmed continued to accelerate, until failure of the batter face occurred at 01:00 a.m. on 16 August. As it was accepted that the wall had started to fail, it was decided by mine management that Harmony would close.

The risks were managed using a combination of controls, all of which contributed to the success of the operation. Geotechnical monitoring and ground support totalled approximately 10% of the mining costs and enabled significant revenue. We had no major incidents and always kept a strong focus on safety as our priority.

## Conclusion

Here we have presented the ground control management process at Leinster Nickel Operations, and how these have been applied in enabling safe mining operation.

Demonstrated is the use of various monitoring and ground support techniques as part of this process. For general monitoring, crack gauges and prism monitoring are relatively inexpensive and minimal time-consuming tools. They are essential for modelling wall failure mechanisms and monitoring long-term trends. Where these systems are inadequate in predicting failure, radar monitoring can be implemented to enable operations to continue safely.

In the case of the Harmony open pit at Leinster Nickel Operations, managing the geotechnical risks using a combination of monitoring techniques and ground support enabled operations to continue for an additional 12 months. The South East wall of the Harmony pit failed early February 2006, 6 months after the pit was closed (Figure 18).

## Acknowledgements

Our thanks go to BHP Billiton Nickel West for permission to publish this paper and our geomechanics superintendent, David Gaudreau, for his support.

## References

HERATH, A. Slope Management, WMC Leinster Nickel Operations, internal document, 2001.

GOODCHILD, D. Harmony West Wall Southern 1C Major Failure, WMC Leinster Nickel Operations, internal document, 2003.

TYLER, D, GOODCHILD, LANGILLE, TERNER, and MORRIS. Harmony Open Pit Peer Review, WMC Leinster Nickel Operations internal document, 2004.

◆