# “YET ANOTHER USE FOR SHOTCRETE”


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## ABSTRACT

In 2003, Independence Group NL purchased the Long Shaft Nickel Mine complex (Long) in Kambalda WA. Lightning Nickel, the nickel operating arm of Independence Group, faced considerable challenges operating the mine, with the most significant challenge being able to prove that the remnant ore at Long and the associated ore bodies could be mined safely and efficiently. Given the seismic history at Long, the magnitude of these challenges could not be underestimated. In an effort to achieve 100% extraction of the flatter ore bodies, traditional methods such as room and pillar were dismissed. A method consisting of transverse sills, butting into each other was proposed. To stop fill material from the first sill rilling into the adjoining sill, it was proposed to backfill the sills with pumped cement fill. The capital cost of the fill plant was estimated to be in excess of $1.5 million and the cost for cement alone was $1.0 million per annum.

Shotcrete was already an extremely useful tool in dealing with the widely variable stress environment, but was to be used in an innovative manner that would enable the full extraction of a tabular section of the Victor South orebody. A layer of shotcrete, approximately 100 mm thick, was to be sprayed on the up-dip wall of the initial development sill. The sill was to be backfilled with "normal" development waste and "topped" with sand backfill. The next sill, i.e. slightly up-dip and alongside, was to be mined along the shotcrete boundary wall. With respect to wall stability, the premise was that the shotcrete wall would stay in place and prevent the backfill (development waste and sand) from rilling into the adjoining development. It was also proposed that any

breaches of the shotcrete wall would be repaired using shotcrete before substantial inflow of backfill into the “new” development.

This paper describes the development and implementation of this mining method, as well as some of the associated financial aspects.

## INTRODUCTION

The Victor South ore body at the Long Shaft Nickel Mine complex (Long) in Kambalda WA, is a group of both steeply dipping and relatively flat (30° to 45°) massive sulphide hosted pentlandite zones overlaying a basalt unit which forms the footwall to the ore bodies. The flatter part of the Victor South ore body lies underneath a steep central core. The ore bodies at Long Shaft and Victor have a seismic history which was presumed to exist at the deeper Victor South orebody. The mining method chosen to extract these ore bodies needed to be modelled to ensure that no deleterious stress effects would result.

With metal prices in excess of A$20,000 per tonne, a variety of mining methodologies were considered in an effort to achieve 100% extraction for the flatter ore bodies which had to be mined before the steeper part of the orebody.

This paper describes the innovative method by which the flatter orebody, Surface 2, was mined.

# MINE HISTORY

A summary of the mine history is presented in Butcher (2005). The Long Shaft Nickel Mine Complex (Long) is located on the eastern flank of the Kambalda dome, south of Kalgoorlie in Western Australia and can be considered to comprise three ore bodies, namely:-

- Long Shaft,
- Victor, and
- Victor South.

An extension to Victor South is the McLeay ore body which lies to the south and beneath Victor South. The deposit is a large ribbon like sulphide deposit striking at 330° and dipping at an average of 67° to the east. The deposit has an overall strike length of 1,700m and a dip length of 600m. In general, the footwall comprises basalt and the hanging wall comprises ultramafic rocks. Figure 1 presents a section through the Long and Victor complex.

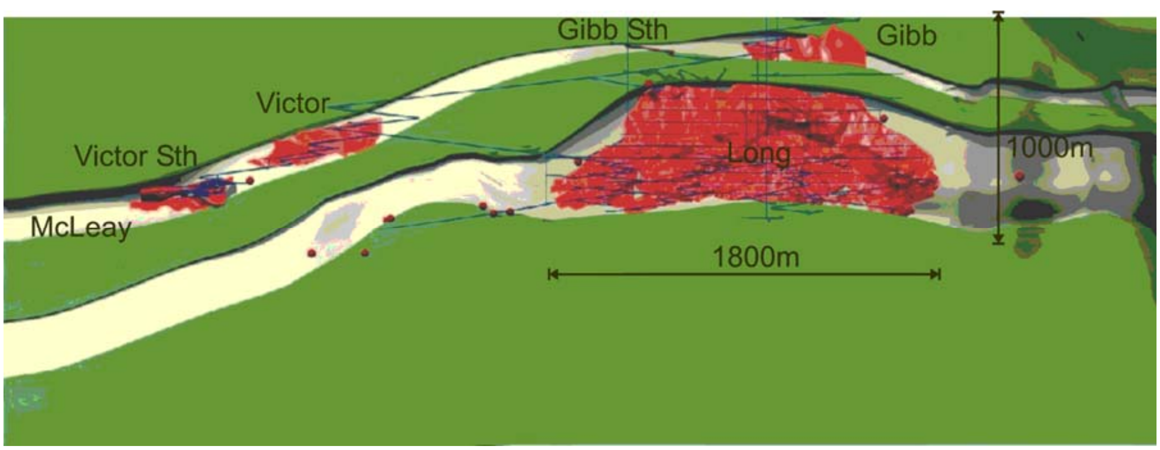



**Figure 1: Long/Victor section.**

Long was discovered in 1971, with the first ore being extracted via a 971m deep shaft in 1979. Mining in the upper levels of Long was undertaken by airleg methods, whilst mechanized methods prevailed in the mid to lower levels of the mine. Decline access was gained to Victor in 1992 and to the lower part of Long in 1998. In 1999, WMC Resources placed the Long / Victor complex onto care and maintenance with some limited stoping being undertaken in 2000.

The Long Complex, including leases, related infrastructure and equipment was purchased from WMC by the present owners, Lightning Nickel Pty Ltd, a fully owned subsidiary of the Independence Group NL in September 2002 and was successfully re-commissioned in October 2002. At that time, the mine had a reserve base of 26,800 tonnes of nickel. Since re-commissioning the mine, exploration and development activities have resulted in the discovery of additional reserves, increasing the current mine life to 2011, based on reserves only. At June 30, 2007 the reserve was 39,600 tonnes of nickel metal. Annual production was 266,442 tonnes at 3.7% nickel for 9825 tonnes of nickel metal.

## VICTOR SOUTH

Victor South consists of a variety of “surfaces” that needed to be mined sequentially from the bottom up, so as not to leave any void areas. A visualisation of the Victor South ore body is presented in Figure 2.

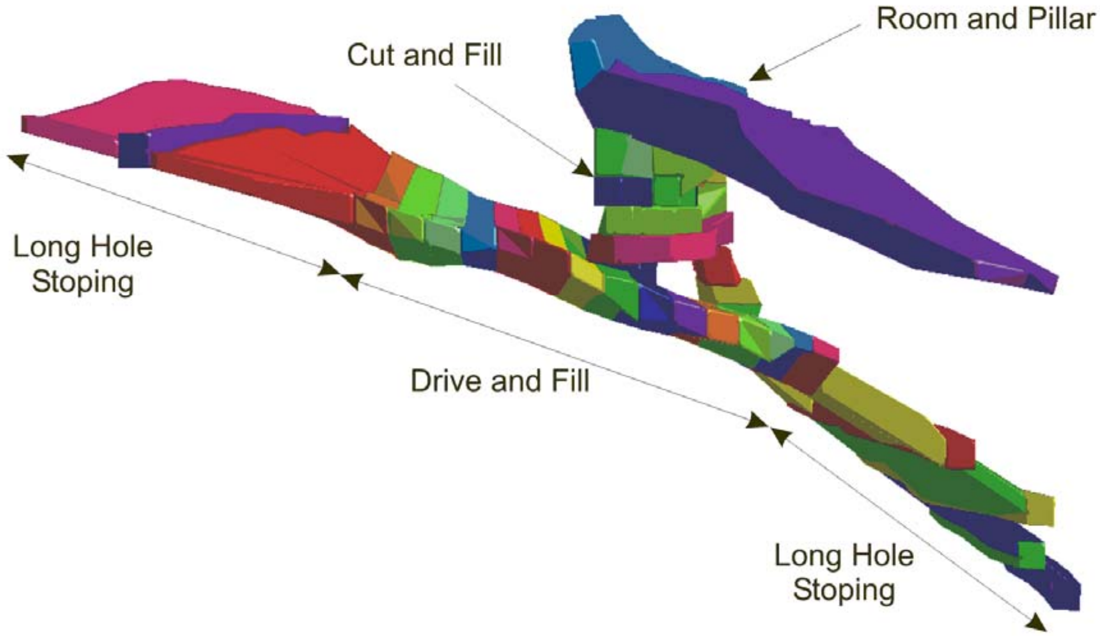



**Figure 2: Victor South visualisation.**

The bottom part of the Victor South ore body, Surface 2, posed typical mining problems. It was a relatively flat dipping surface, 35° to 45° and narrow in width, as shown in Figure 3. The most positive aspect was the high nickel grade (3-5%). With nickel prices in excess of A$20,000 per tonne, a method by which maximum extraction could be achievable was desired. One method considered and quickly discounted was a form of room and pillar extraction, as the value of any remnant pillar was too great to be left in-situ. Also, this method did not allow for safe and simple post pillar extraction.

In mid 2005, other methods under consideration were based around cemented backfill and 100% extraction.


**Figure 3: Photograph of Victor South ore body exposure.**

## TYPICAL MINING METHODS

The mining methods that were considered included:

- Sand Backfill
- Cemented Rock Fill
- Paste Back Fill

## Sand Fill

Existing sand fill infrastructure exists at Long enabling the possibility of sand filling of stopes at Victor South. Sand fill can be purchased from BHP Billiton's concentrator located about 2 km from Long Shaft. The sand fill is transported by truck to a holding area at Long, where it is sluiced / pumped via boreholes to the stopes.

The concept of using sand fill allowed the drives to be tight filled. However, if the adjacent stopes were to be mined, there was a possibility of sand running from one stope to another. The simple solution was to leave rib pillars along the drives, but the inherent nickel value in these pillars made this option undesirable.

## Cemented Rock Fill (CRF)

The simplest was a Cemented Rock Fill (CRF) system. Drives across the strike of the ore body were to be undertaken and cement mixed with rock in a simple sump. The CRF was then to be placed in the drives via the use of CAT 1700 loaders. This method posed some practical problems, including that the rate at which the drives could be filled was expected to be slow and this in turn would tie up valuable production loaders and manpower. It would also be practically impossible to tight fill stopes and the cost of the cement in the fill was significant.

## Paste Fill

The mine operators believed that the concept of traverse mining of the ore body should form the basis of any other approach to the mining of Surface 2. Lightning Nickel decided that any Paste Fill or Cemented Hydraulic Fill (CHF) system should be designed so as to enable drifts to be efficiently filled and that the system should have a capacity of 5,000 to 8,000 fill tonnes per month.

A capital estimate undertaken by COMO Engineering showed that a 500 tonne per day of Paste Fill plant would cost approximately $1,500,000. The cost estimate was in excess of the initial scoped amount of $400,000 to $500,000. In addition to the $1.5M capital cost, the anticipated operating costs per year were approximately $1M. At cement cost of approx. $220/t a mining rate of 5000t/mth and an additional rate of 7% the cement cost alone would be $77,000 or $925,000 per annum.

It was expected that this plant would be in operation by the second quarter of the 2005/06 financial year (Victor filling was required from Mid November 2005 and therefore cemented filling capacities needed to be investigated to reduce production risks).

Due the slow rate of filling with CRF and the lack of structural integrity with sand fill the paste fill, even though expensive, appeared to be the best option

From a technical point of view, paste fill provided an excellent solution, but with significant costs and risks to production. A series of studies, including costing, were undertaken to determine how such a solution could be integrated into the mining cycle but the costs, complications, uncertainties and production risk forced the mine operators to seek another solution. To this end, a meeting was held between the mine operators and Mining One Pty Ltd.

## ALTERNATIVE METHOD

When considering the paste fill option, the favoured mining approach / concept was to drive across the orebody and to remove any pillars on retreat and backfill with paste. Using this broad concept as the basis for mining, a “brainstorming” session with the mine operators was held on site. A question posed in this session was related to the possible use of rock backfill in the drives. The main issue in this regard was that if unconsolidated mullock fill was used in the stopes, like sand fill, it could rill from one drive to the next if the pillar between the drives was breached or failed. The use of mullock fill was highly desirable as it was inexpensive and could be placed in the drives quickly without an excessive demand on the existing mobile fleet of trucks and loaders. It became apparent that the solution lay in the ability to consolidate the fill alongside the next stoping drive. One suggestion was to leave a thin pillar between drives, however, mine operators acknowledged that the integrity of this pillar could not be guaranteed. There were even concerns about how much stress this pillar could be subjected to. The premise that the pillar would "take weight' was to some degree dismissed after much discussion, as it was expected that stress would redistribute around the mine workings, leaving the backs in a relatively unstressed conditions whilst abutments would experience higher stress levels. Once an understanding of the expected stress level was gained, a somewhat novel notion evolved.

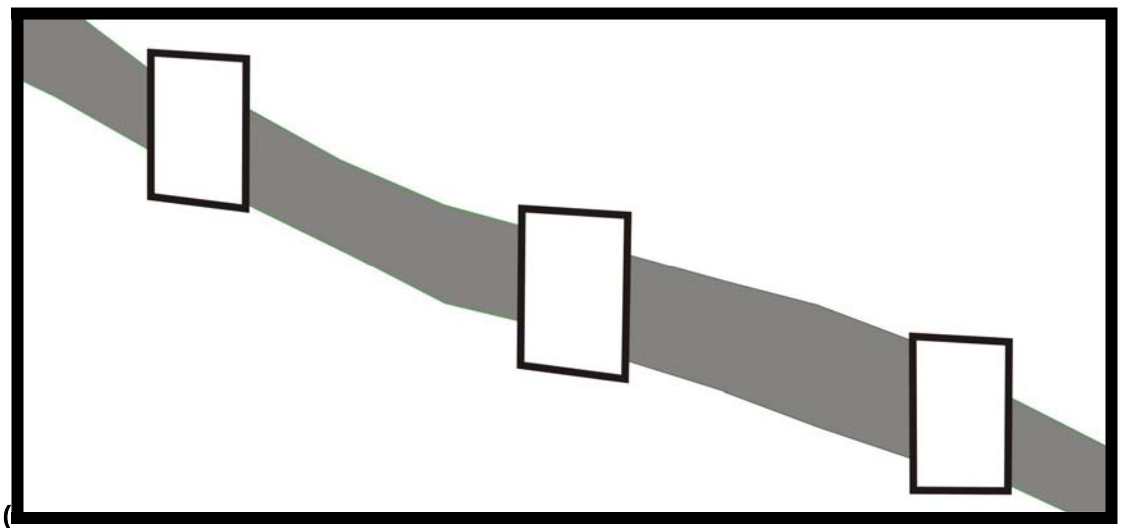
It was suggested that the surface of the waste rock backfill could effectively be sealed using shotcrete. If this could be done, the stability of the fill could be substantially improved. This would obviously be impractical, however, a variation on this theme was suggested and pursued, where both sides of the thin separating pillar would be shotcreted. If the shotcreted pillar remained intact, or was repaired as mining progressed, this would stop the fill rilling from one drive to the other.

**The proposed alternative solution put forward to the mining operators was as follows and outlined in Figure 4a - e:**

1. The up dip side of the first drive would be bolted, meshed and shotcreted (4a and 4b)
2. The drive would then be filled with unconsolidated waste rock (4c)

3. The remaining voids where the waste rock was not in contact with the backs would be close filled with sand fill (4d)
4. The next up dip drive would be mined along the previous at a minimal offset of 250 mm (4e)
5. The down dip side of the new drive would be shotcreted as the excavation processed (4a and 4b)
6. Any areas where the pillar between the two drives failed and down dip fill was breached would be immediately shotcreted to contain any rock or sand fill

**To ensure production continuity, there would be three, approximately parallel drives as initial "sills" where the above sequence would be implemented**



(

7. Figure 5 Cross Section of Surface 2 showing position of initial drives). The final extraction of each of these, except the upper most drive, would abut the sill of the next drive leaving three abutment pillars.

If this conceptual mining method worked, there would be considerable capital and operating savings. There was also the possibility that 100% extraction could be achieved.

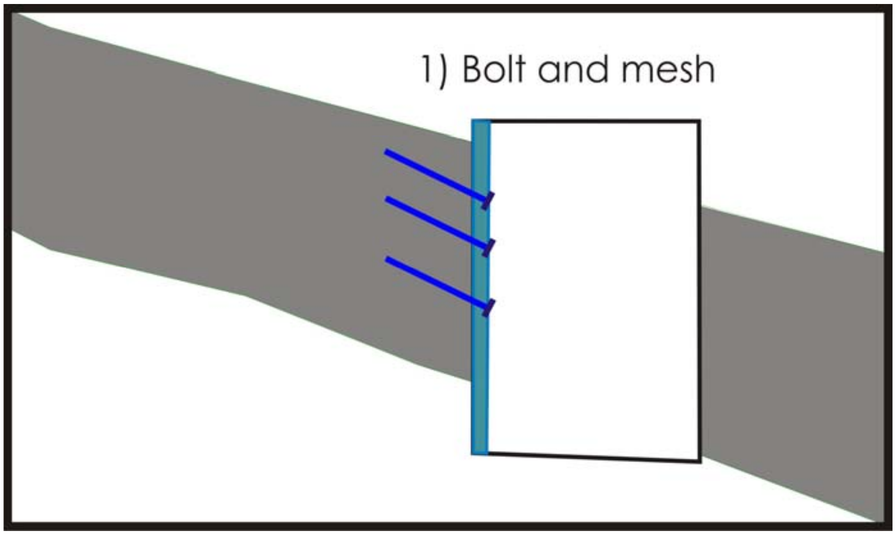



**Figure 4a: Initial drive bolted and meshed**

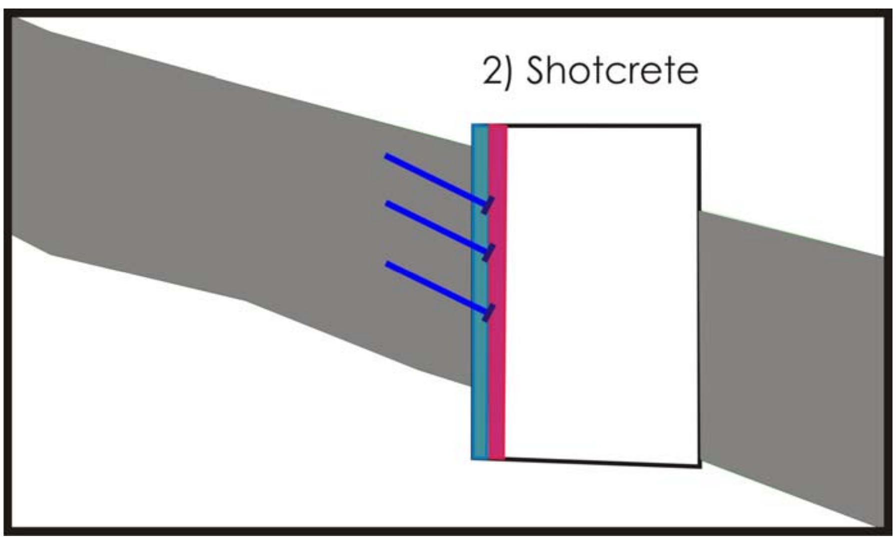



**Figure 4b Shotcrete sequence**

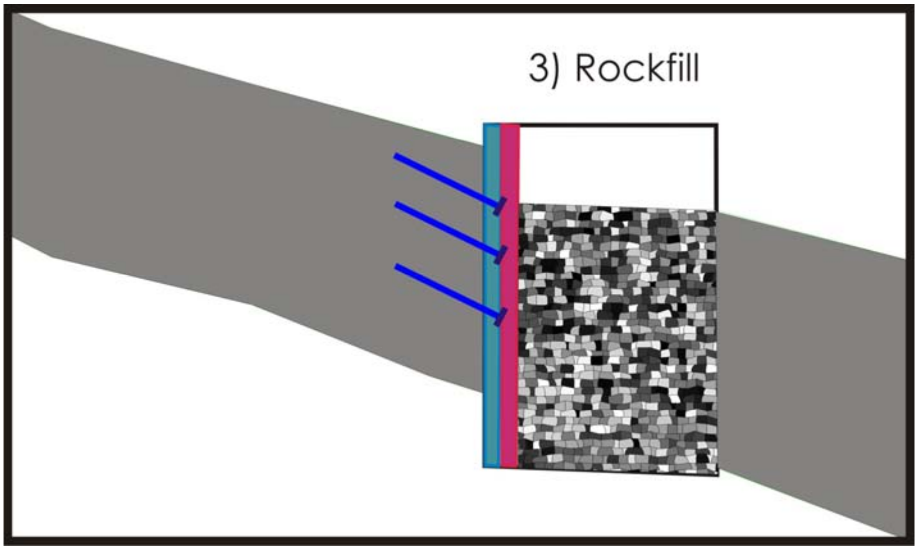



**Figure 4c Filling sequence (Rockfill)**

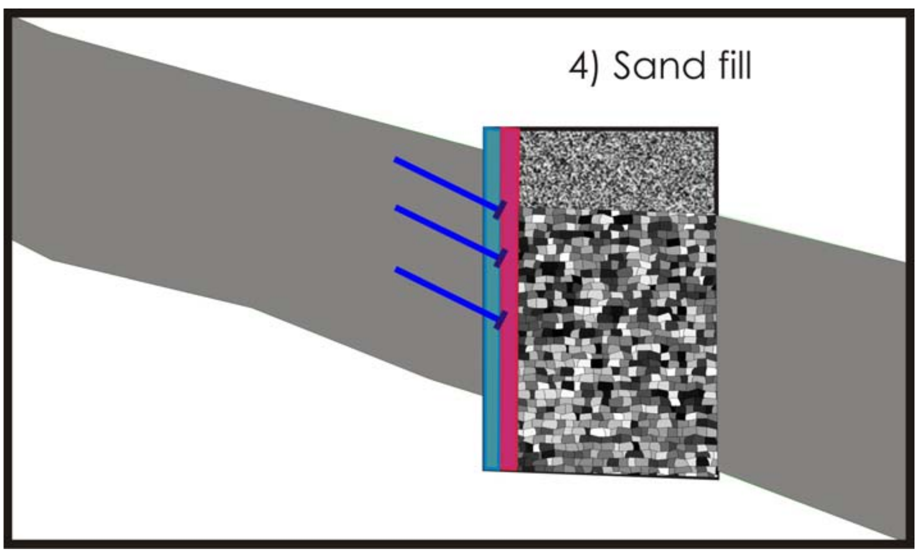



**Figure 4d Filling sequence (Sandfill)**

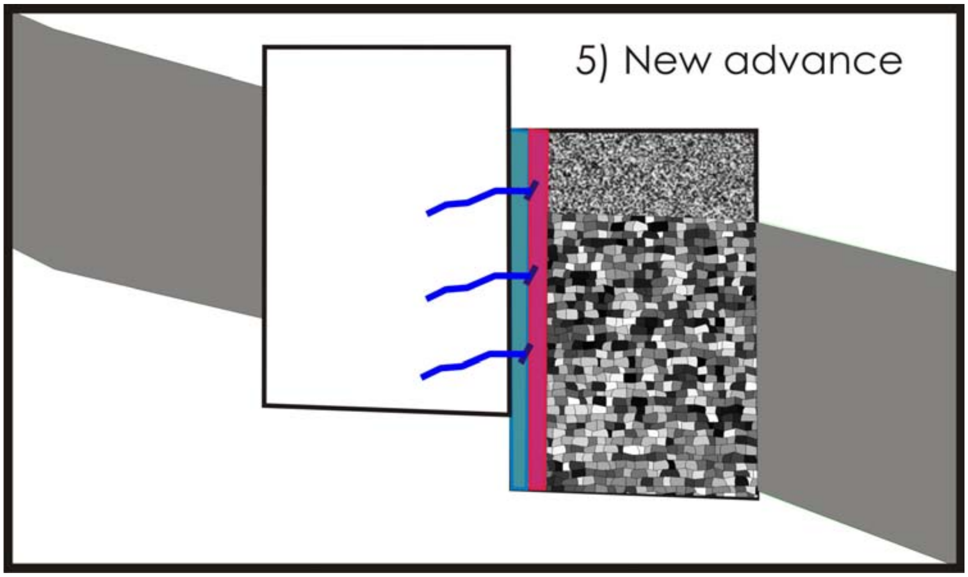



**Figure 4e Subsequent Driving**

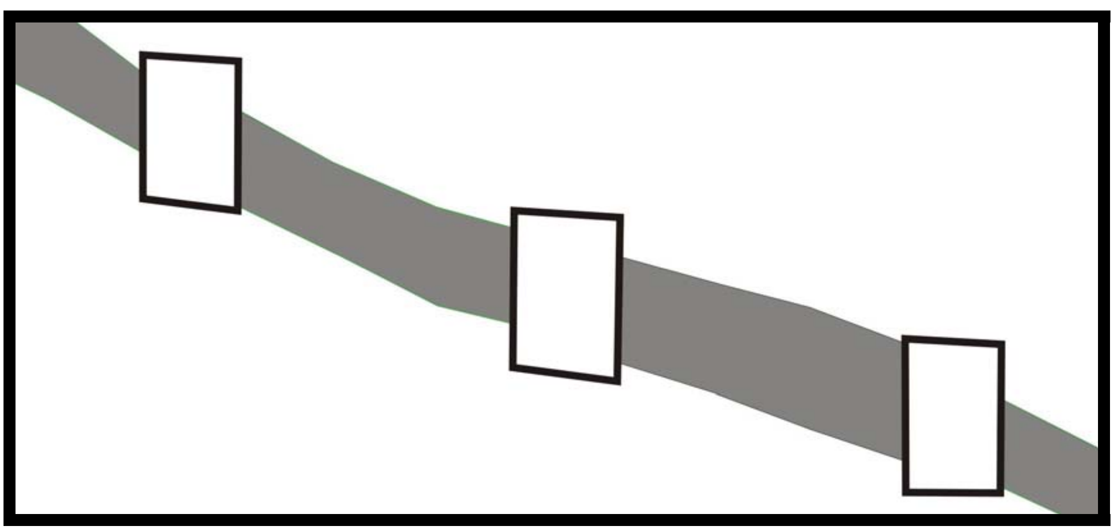


**Figure 5 Cross Section of Surface 2 showing position of initial drives**

## GEOTECHNICAL STUDY

Mining One undertook 2D and 3D modelling of the proposed mining method using Phase2 and MAP3D software to assess whether the proposed mining method was feasible and to investigate the main issues in respect to stability. Various mining sequences were modeled by Mining One with the aim of estimating the level of overstressing, if any, that the pillars would experience as mining progressed and if eventual full recovery of all of the ore in Surface 2 could be achieved.

The MAP3D modelling results indicated that when the pillar width was reduced to 5m, the pillar stress increased substantially. This was deemed as a critical point in stability. Figure 6 shows the differential stress ($\sigma$ 1 minus $\sigma$ 3) build up as the pillar width is reduced.

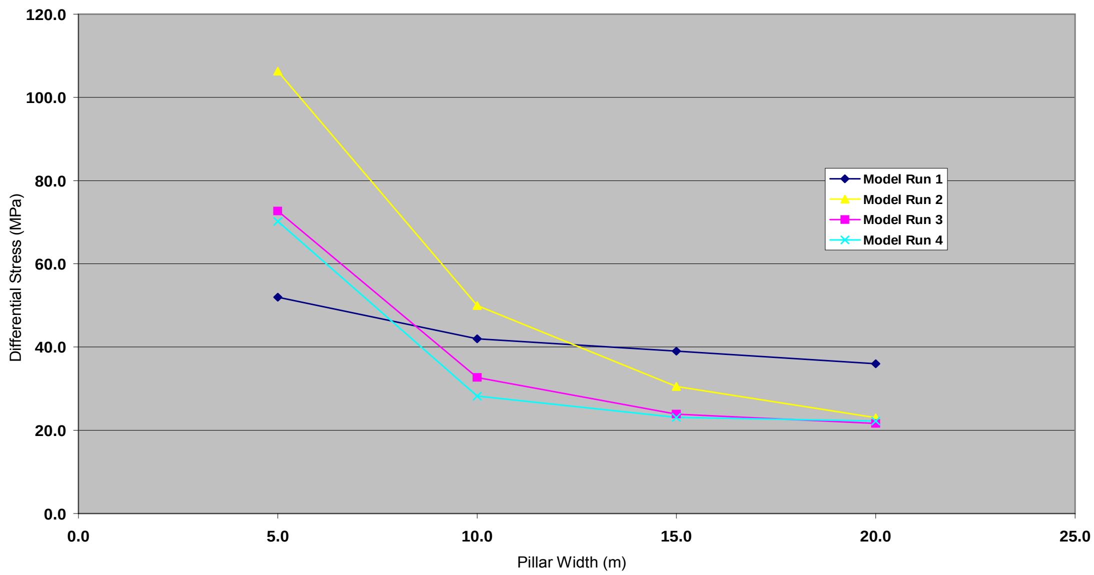



**Figure 6: Differential pillar stress with pillar width.**

The modeling results also confirmed the expectation that the backs would experience relatively low stress levels compared to the abutments. Stresses at the end of the mining sequence were shown to be relatively high in abutments. However they were not in excess of the strength of the rock and were not expected to pose mining problems.

Modeling using Phase2, a 2D finite element software package developed by Rocscience, was undertaken by Mining One and included completing numerous sensitivity runs on the following parameters:

- Shotcrete Thickness
- Shotcrete Properties
- Mining Sequence
- Backfill Properties
- In-Situ stress conditions

As with the MAP3D results, the Phase2 analysis indicated that when the pillar width was reduced to 5m, a large increase in stress occurred within the pillar and de-stressing occurred in the backfilled span between the pillars. This can be seen in Figure 7, which shows the $\sigma_1$ stress contours when a 5m pillar is remaining in the three mining blocks.

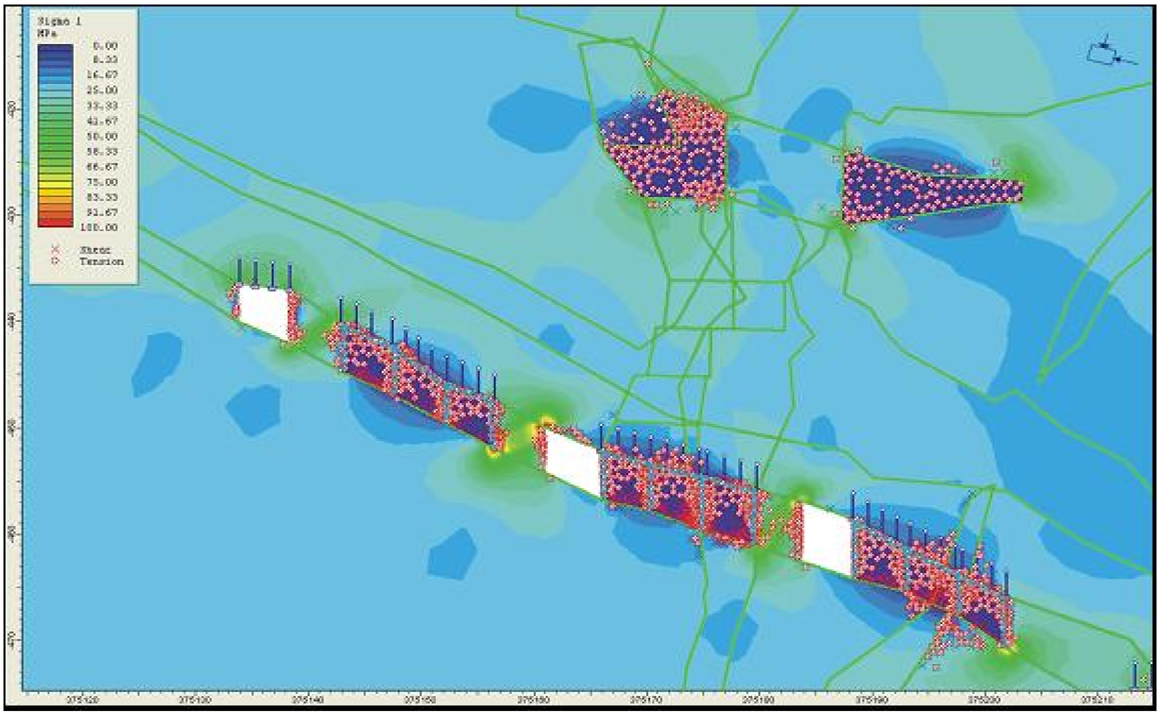



**Figure 7: Phase2 output for 5m pillars showing yielding and $\sigma_1$ contours.**

Figure 8 shows the corresponding strength factor within the pillars, with white indicating a strength factor above 1.2.

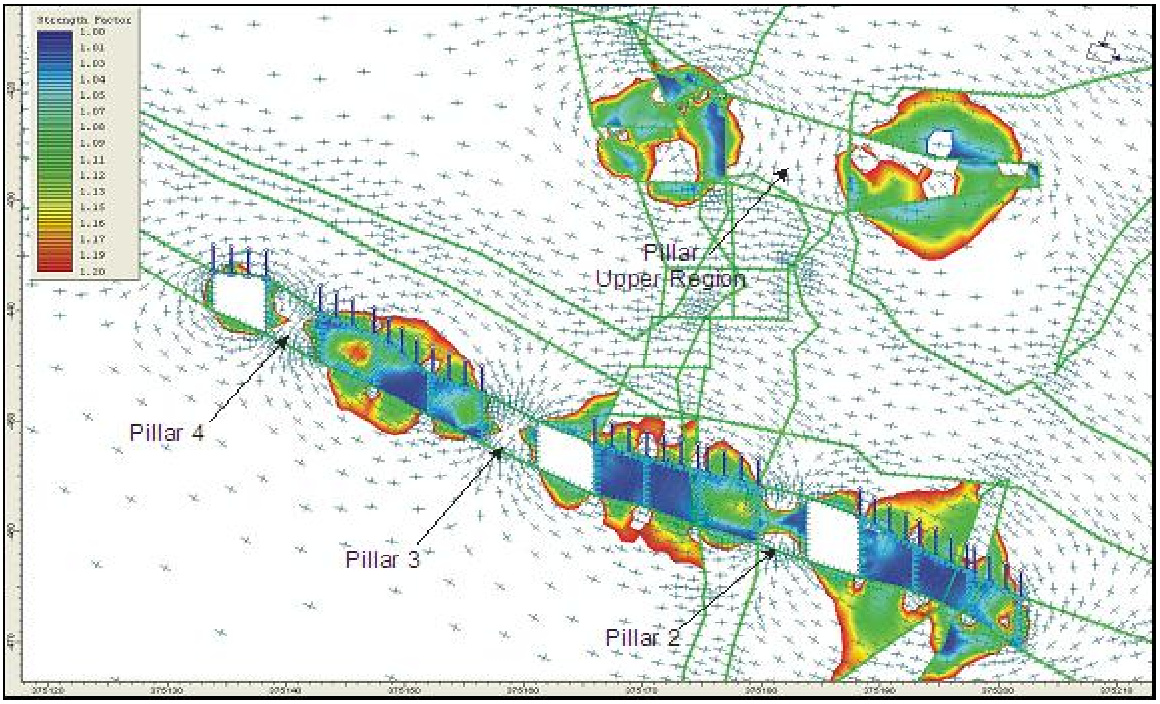



**Figure 8: Phase2 output for 5m pillars showing strength factor contours.**

The modelling undertaken by Mining One identified that a number of critical issues, as outlined above, would develop and the mining method / sequence would require attention by the mine operations. These were as follows:

• The backfill in the drives needed to be as tight as possible to control the inevitable relaxation of the backs as the span increases increased in the mining method.

• A high strength shotcrete, 100mm thick, would be required to withstand the backfill pressure.

• As mining progresses, it would be expected that more shotcrete would crack and fail and require rehabilitation.

• When the pillar width between mining sequences reduced to 5m, the stress would increase and hence mining the last pillar was expected to potentially be difficult.

• A large relaxation zone would develop above the backs when the surface 2 mining was completed. Careful mining of the remaining vertical central zone would be required.

Lightning Nickel successfully dealt with the conclusions from the modelling and Mining One's recommendations by changing their mining methods to minimise the potential effects identified.

The changes entailed that the last drive, as it abuts the upper sill, would not be driven in the same way as the others. Instead, the ore from the upper side of this penultimate drive would be slashed on retreat and bogged with remote control loaders. After each firing, for example approximately 15m across strike, the stope would be backfilled with waste rock, again using remote control loaders. At the final position, such as the end of the retreat out of the drive, a barricade would be built and the stope would be tight filled with sand fill. This methodology mitigated the need to approach the abutment pillars that were expected to be highly stressed.

# IMPLEMENTATION

## Trials

The ability to mine along the shotcreted wall was the key element to the success of this mining method, so a trial drive in an unrelated area was undertaken.

The trial drive was shotcreted with a layer of shotcrete approximately 100mm thick, bolted with split sets and back filled as previously described. A parallel drive was then excavated next to this with a nominal offset of approximately 250mm. Shotcreting was undertaken as the second drive progressed.

The trial drive and mining sequence was a success. Some minor breaches occurred at the “down dip” or first drive, however the combination of both shotcreted walls maintained the stability of both drives.

## Full implementation

The mining method was adopted for Surface 2, albeit with some modification to accommodate the high stress expected in the remnant pillars less than 5m in width. Stoping began in 2006. The backfilling of the initial drives with unconsolidated fill was simple and efficient. A significant effort was made to push the rock fill as close to the backs as possible, to reduce the volume of sand fill required. Thick shotcrete was placed along the wall of the drive as bolting took place (in cycle) to ensure its integrity for up-dip mining.

## Shotcrete

At the beginning of mining operations, Lightning Nickel made the decision to undertake “owner operated” mining. As a result of this decision, shotcreter and agitator trucks were purchased. Mining One proposed that a custom built shotcreter and agitator truck would provide similar cost benefits as had been experienced at other sites. Lightning Nickel agreed to take this path. Mining One staff managed the project of building the shotcreter and small agitator which enabled Lightning Nickel to use shotcrete in an extremely cost efficient manner. This efficiency was further enhanced by Lightning Nickel’s purchase of a batch plant, thus reducing shotcrete costs even further.

Whilst the efficiency of the shotcreting was extremely good, possible improvements existed by batching underground which would provide a reduction in time and cost for this activity.

The use of shotcrete to prepare and repair the inter-drive pillar was untested other than in normal mining operations and the trial drive.  The use of shotcrete of varying thickness to "repair" failed mining surfaces was common at Long and presented the mine operators with new challenges.  The concept that this would consolidate waste rock however had to be "sold" to certain operating staff and was successfully done so by viewing the performance of the shotcrete in the trial drive.  The decision to use a 100mm thickness was an arbitrary one, albeit one that was accepted and confirmed after geotechnical modelling.

## Mining

The mining and support of the first or down dip drive was very simple, although extra care was taken to ensure that the drives were mined straight so they could be followed in subsequent up dip driving.  Figure 9 shows the prepared surface of the initial down dip drive at 465.

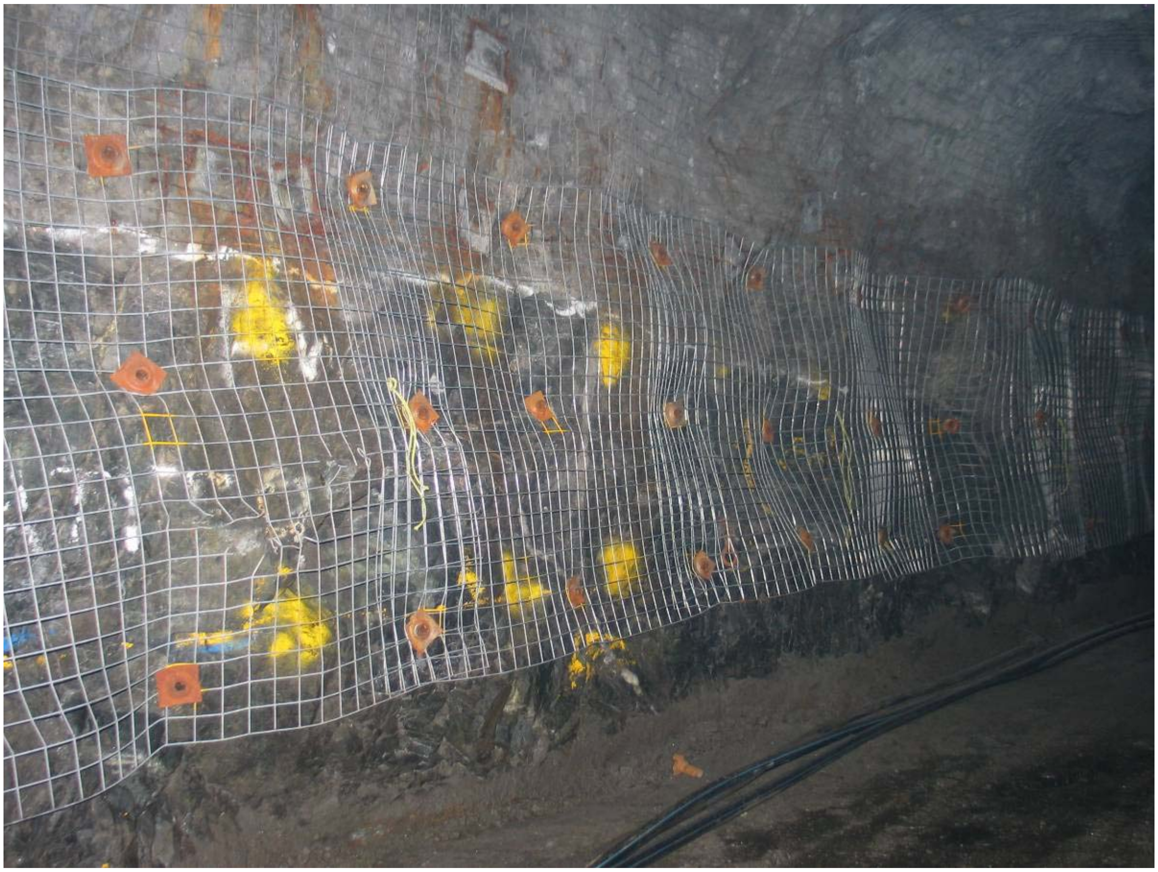


**Figure 9: Preparation of the up dip wall, ready for shotcreting at the 465 drive.**

Mining of the up-dip drive proved extremely successful. The stoping, or up-dip drive method paralleled the experience of the trial drives. Care was taken to ensure the driving was straight and followed the edge of the down dip drives.

Occasionally the fill from the down dip drive was breached. However the standard procedure was to repair any breach immediately with shotcrete. This resulted in containment and the lessening of the consequence of any breach. It was planned that if a substantial amount of fill, particularly the sand fill, rilled from the down dip stopes, a mesh barricade could be installed on the wall and the shotcretor used to pump lean concrete mix behind the barricade. The shotcretor had a concrete pump capable of a pumping rate of 25-30 $m^3$ per hour, so this contingency was thought to be well covered. In practice, the situation never arose so this contingency was never tested.

The overall mining approach was enhanced by the dip of the ore body. The down dip part of the ore-body only partly “daylighted” in the up dip drive. Essentially, the up dip drive only required stabilisation up to the mid point/ shoulder height. The placement of shotcrete enabled this to be done effectively and efficiently. As a result, dilution was reduced to a minimum. The lowest part of the down dip drive was below the floor of the up dip drive.

The condition of the backs of the drive, although expected to be of some concern, proved to be very good and did not show the signs of the relaxation that was expected. A photograph showing the condition of the back is presented in Figure 10.

**Figure 10: Condition of the up dip exposure at 465 before shotcreting.**

In this method, mining “consumed” the slim pillar between the drives. The split sets that can be seen are those placed from the previous drive. From this point, the drive was shotcreted and any remaining split sets were cut away. If it were not for this skin of shotcrete, the plates that stabilise the fill would rill into the up dip drive.

Mining next to the abutment pillars went smoothly, other than some poorly drilled holes that created a significant amount of over break in one drive. This increased the dilution for that firing and necessitated an increase in the amount of sand fill that would normally have been required to fill that stope.

Mining continued through January 2006 to May 2007 i.e. on schedule for the extraction of 55,487 tonnes at a reported grade of 4.22% nickel. If the room and pillar method had been used, it is estimated that approximately 30% of the ore could not have been recovered. Using a nickel price of A$30,000/tonne, this equates to approximately A$21,000,000 worth of nickel that would have been left in-situ.

No lost time injuries occurred during the mining process.

## CONCLUSION

The use of shotcrete to retain the fill in the drives and the fill mining method proved to be extremely successful. The concept behind this methodology was developed by the mine operators and therefore had great support on the "shop floor".

Capital and operating cost savings were significant, estimated to be approximately:

- A$1,500,000 capital, and
- A$1,000,000 operating costs /year.

More shotcrete was used than in other more commonly used methods. However, the cost of additional shotcrete, whilst significant, was reduced to approximately $600/m$^3$ by the mine operators owning the equipment and by on site batching thereby proving to be insignificant compared to the capital and operating cost the previously preferred method, paste fill. The mining method allowed nearly 100% extraction with significant capital and operation cost savings over other preferred methods.

The real success was the ability of mine operators and their consultants, Mining One, to "think outside the square". The recognition that there was no need to consolidate all of the fill and the ability to turn this into reality by the staff at Lightning Nickel is an example of the clever thinking that has enabled mining at the Long/Victor complex to be undertaken so that safety and ore extraction is maximised, and costs are significantly reduced.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| Michael Bijelac | Mining One |


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