SUPPORT CHALLENGES AND EXPERINCES ON PALABORA BLOCK CAVE - INITIAL MINING THROUGH TO FULL PRODUCTION.

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Abstract

Palabora Mining Company currently operates a large (32000 tpd) block cave, designed for a life of 20 years. The mine is mining the hardest rock to be caved over the highest height of draw (HOD). Some of the work done at the feasibility study was correct, but some assumed conditions were not experienced and were therefore incorrect. During the construction of the mine these recommendations, either correct or erroneous, were not followed!

The paper deals with the original design of the support through to the support as installed. There are 314 drawpoints that will yield upwards of 500 000 tonnes of ore. Weekly monitoring of these drawpoints is done and steel brow sets are retro fitted (the feasibility decision was not to fully equip the footprint with brow sets). This retro fitting is not done elsewhere in the block cave community, and systems for working under operational drawpoints have been developed on mine to facilitate this. The sets were also not available ‘off the shelf’ and a design to suit had to be developed and then manufactured.

During the mine’s construction, the undercut geometry designed as a diamond shape approached a seismically active dyke at an unfavourable angle which required management. Later the final mining of the undercut to the west proved to be a challenge - a large fault zone deep in the pit wall caused abutment stresses to load up the area between the fault and the undercut, requiring a call to be made in support strategy and mining rate.

Modelling done prior to mining also failed to highlight the pit wall failure which has occurred. This caused 130 million tonnes of material to report to the pit bottom, which has affected the draw control strategy for the cave material.

The author has been involved with the project, from 1999 when shaft sinking was still being completed and the first undercut blast taken, through all of the learnings to full production at over 32000 tonnes per day, hoisted out of a single shaft. Many papers discuss what has been designed and what is planned. This paper will attempt to discuss how support decisions made affect later mining, and to describe challenges to find the correct support type and the work done with local suppliers to find solutions.

Many decisions made would be different next time. Nevertheless, Palabora Mining Company has operated over the past two years with no rock related injuries (fatal/reportable/lost time/medical treatment/first aid).
1. Mine location and description

Palabora Mining Company operates a copper block cave mine in the Limpopo province of South Africa. The mine was developed in the late nineties with a target ore reserve of 240 million tons of Carbonatite at 0.70% copper. At 30000 tons per day the operation had a planned life of mine of approximately 23 years.

The production level (extraction level) sits at a depth of about 1200m below surface and 14m below the Undercut level used to initiate the caving. Column height ranges between around 400m directly below open-pit floor and 750m on the furthest columns in Western extent of the footprint. This is currently the highest lift ever to be caved. Feasibility study results indicated that production rate of 30000 tonnes per day will ensure financial viability for the project. This has changed and current call is 32000 tpd with the call increasing again for 2008.

![Figure 1: Layout and structure – Production level](image)

The Palabora block cave is serviced by a service shaft, a ventilation shaft and a production (rock handling) shaft with a herringbone production level layout consisting of 166 draw bells. Tonnage is currently drawn from 314 drawpoints. Diesel LHD’s load ore from 19 cross cuts and tip into four 750t/hr jaw crushers. The footprint covers approximately 100 000m².

2. Introduction

The challenge to a Rock Engineer is, (roughly quoting the original Chamber of Mines coursework for the Certificate in Rock Mechanics), to adequately support the excavation for the planned life of the excavation most economically to the mine.
One of the challenges with a low grade block cave is to fulfil these functions. Once the initial feasibility has been through to the financial Board and been rejected, the further versions of this feasibility study then had a fair amount of “pencil sharpening” done, and some of the required support capital fell away. This will be discussed in more detail, but much of the shotcrete that has actually been placed was not planned for, in the belief that the ground was ‘good enough’. Certain support systems advocated for the undercut were changed in the interests of safety and speed, and the installation of brow sets was limited to only the ‘worst’ drawpoints. The challenge for the Rock Engineer was then to decide when and where to spend unbudgeted money and be able to validate decisions made.

Figure 2: Palabora open pit showing integrity of the benches.

Palabora open pit was a highly successful pit (Figure 2), with pit angles of $57^\circ$ and beautiful square benches standing stably from when the mine was begun in 1964. A lot of talk in the industry at the time discussed the plan to block cave the extension of the ore body below the mineable extent of the open pit. At that stage the Palabora Block Cave was planned to have the highest HOD (Height of Draw) and would also be the hardest rock to be caved. Many people in the industry believed that the rock was “too hard to cave” at 120 Mpa. Palabora sits right on the unexplored side of the “caveability” graph (base graph after Hoek 1981).
3. Block cave support

In a conventional tabular mining layout the support utilized is finite and certainly in ‘follow on’ footwall drives has an expected life of around 6 months. In block caving the whole mining footprint and the ancillary chambers for pumps, crushers, workshops, etc are all developed before the tonnes flow out of the shaft. This also means that the money spent on, in Palabora’s case, 33km of development, is spent ahead of the generated income. Support installation also needs to infringe as little as possible on the operational part of the cave.
Palabora’s rock hoisting shaft currently does the highest tonnage of any single shaft in the world.

- Best day – 42998 tons (May 2005)
- Best week – 36819 tpd (Week 24/2007)
- Best month – 1 073 280 tons (35776 tpd April 2007)

To achieve this the cycle needs to run ideally with no interruptions - to take crosscuts down for frequent rehabilitation and re-support is not conducive to this. Therefore the support has to be:

- Correctly designed for the life of mine (at that time + 20 years).
- Economically practical as some of the funding was already reduced at feasibility.
- Allow for remote and therefore safe installation.
- Rapid in terms of both installation and re-entry.

4. Support challenges (Rock Bolt system)

Primary support on the mine has been done using 2.4m (length of the bolter boom) 20mm re-bar with full column resin grouting. Using the Tamrock bolters at that stage the drill steel was 25 AF, but had an actual diameter of 28mm. Using knock off bits the skirt on the bit was prone to shearing if too small a diameter bit was used. A 32mm bit was the smallest that could be used. The *Australian handbook for hard rock mining* advocates an annulus of resin of around 2mm. The annulus found at Palabora was 6mm. Work with local suppliers came up with a resin with a 70:30 mix ratio that could be used with an annulus of 6.5mm. The use of a 25mm or 28mm bolt was not required from a support point of view so work was done on the 20mm bar. Eventually a solution was found where a cold rolled thread was introduced on a bar resulting in a 22mm x 20mm bar with two sets of half threads. Pull tests show this combination to work exceptionally well.

5. Support challenges (Brow sets)

It was expected that only around 15% of the 314 brows on Palabora would need sets to be installed. This was due to financial considerations and the belief that the rock, being so hard, would not require solid support.

The first issue was to obtain sets other than the ‘Walter Bekker’ (T&H Mining) yielding arches. The other companies that used to manufacture what was then (wrongly) referred to as “Square sets” had concentrated on manufacturing yielding elongates for a huge market in both the local Gold and Platinum mines, and locally manufactured sets were therefore unavailable. Several of the yielding arches were installed, but although an excellent arch for highly stressed ground, they were not designed for the use they were being put to. In a block cave the set should not generally be subjected to high stresses, but is required to assist the support system to hold the whole drawpoint area together. The set also provides a wear platform for the rock that will pass through the bell and drawpoint, in Palabora’s case, between 500 000 and 750 000 tonnes of material. In the dolerite dyke rich drawpoints, the passing rock is highly abrasive having a UCS of over 300MPa. In the softer, but more blocky Carbonatite, large oversize rocks reporting to the drawbell need to be blasted. Higher hang-
ups are brought down using a ‘Medium reach rig’ where a 75mm hole is drilled in the rock and blasted with HEF, an ammonium nitrate slurry explosive. Blasting is not to take place immediately against the brow, but it is undertaken only metres away.

The yielding arches did not support the brow or provide an adequate wear platform. Investigation was then done, looking at sets used worldwide. Designs from Henderson, NorthParkes, Freeport and more locally Premier mines were all studied. A combined design was generated and put together by engineers on Palabora Mining Company. This was sent out to local steel works and the design has gone through three stages of design modifications to the current one that is used.

Figure 4: Palabora design for “Stiff Brow” support

At a stage during the development it could be seen that the installation of brow sets was going to be required, and from crosscuts 16 through to 20, all drawpoints were then equipped with sets. The whole remainder of the footprint was in operation with now the challenge to get 30000 tonnes per day. The challenge was having to come back and retro-fit over 200 sets with out introducing any constraints on the operational cycle.
On investigation it was found that mines world wide do not have a lot of experience in doing this sort of retro-fit construction. Palabora had to come up with a system to install support in operational drawpoints without putting persons at risk, and ensuring that the installed brow support was in fact placed under the brow.
The drawpoint had to be in a free-flow condition as opposed to being hung up, since the exposure to personnel should this hang up come down was unacceptable. As shown in Figure 6, the upper metre would be shotcreted with wet fibre reinforced shotcrete (FRS). Once this had cured spiling was drilled in, often in the form of old drill steel. The lower portion of the muck pile could now be lashed and another metre of shotcrete applied and new spiles installed. In this manner the whole face could be safely shotcreted and supported and effectively, completely shielding the construction crew from the open cave above them. A vertical face is formed of shotcrete placed at a thickness of 300mm. The work on this shotcrete design has allowed for the spiling to be dropped, and a system now exists for the installation of a brow set in less that a week, from start to finish, and handed back to operations. Around 54 sets per year are retro fitted.

6. Footprint support

All primary support was, as discussed, 20mm bolts, full column grouted with resin. All breakaways were supported with 6m long, 18mm pre-stressed cable anchors and OSRO straps with another two sets of anchors and OSRO straps at the brow position. Bolts and OSRO straps replaced trusses on the ‘bullnoses’ and ‘camel backs’. The whole footprint has been shotcreted with initially steel fibre (40kg/m$^3$) reinforced shotcrete and later with polypropylene fibres (9kg/m$^3$).

Figure 7: Support layout for the Production Cross Cuts and Drawpoint entrance
7. Support monitoring

Monitoring in the footprint is done around the clock. Geotechnical observers work on all three shifts taking readings. Brow measurements are taken in every drawpoint on a weekly basis and data for these is available from when the drawpoint was first mined up until present, and can be cross referenced against tonnes drawn, and geology.

Brow monitoring relative to the crosscut’s breakaway position is picked up using a remote laser instrument (Distomat).

Figure 8: Support layout for Drawpoint and Bell area

Figure 9: Brow wear monitoring
Readings are plotted against tonnes to obtain wear rates, and drawpoints are prioritized for set installation. All drawpoint lengths below 9m are noted, drawpoints with lengths below 8m become short listed for rehabilitation, with the sub 7m drawpoints getting retro-fit sets installed.

Graph 1: Brow wear measured in crosscut 1

The wear on the brows is shown in Graph 1. Here relatively rapid wear is seen in the first part of draw and certain drawpoints can be seen to be wearing faster than the others. Where the plot stops is the point where a retro-fit set has been installed.

Graph 2: Tonnes drawn crosscut 1

Tonnes drawn for the drawpoints are shown in Graph 2. Over time a gradual increase in the monthly draw can be seen. This relates mostly to the fragmentation size reducing over time
with an increasing HOD. What is of most interest is that the wear in the drawpoints is very heavily affected by the local geology and blast related fractures, which leads to high initial wear and a very shallow residual tail to the graph. Features that run parallel to the brow do not affect the brow much. The damaging geological structures are the ones that run perpendicular to the brow. Mapping of all structures during the development stage before shotcrete is applied is vitally important.

8. Convergence monitoring

Convergence readings are taken on a twice weekly basis from all of the stations. These are taken from sets of 3 point stations throughout the mine. The readings are also cross referenced against the tonnes drawn from the drawpoints, and in this way the influence of overdrawn or underdrawn drawpoints is observed and monitored.

![Convergence stations](image)

**Figure 10: Convergence stations, Strain gauges and Extensometers**

![Convergence station setup](image)

**Figure 11: Convergence station setup**
Movements seen have very interestingly shown that the Carbonatite does behave elastically. With a monthly production rate of over 1 million tonnes small changes in the rockmass can be related to the evenness of draw and also the local geology. Over 4000 individual convergence setups are done on a month by month basis. With the rock behaving in an elastic manner it is important that the choice of support has an elasticity to it. Tendons should have the ability to deform to the small increments that occur in the footprint.

![Production - Week 45](image)

**Figure 12: Tonnes pulled from the cave week 45**

Higher tonnage was drawn on the southern side of the footprint during week 45 as shown in Figure 12. This shows reasonably even draw elsewhere in the cave apart from crosscut 11 which was closed, and crosscut 8 which was on rehabilitation.

*Figure 13* shows the plotted movements within the cave for the same period. Although very small, the movements show that the area where the higher draw relative to its sister drawpoints took place underwent a slight “rebound”.
9. Conclusions

In conclusion, a number of points can be made:

- The most important factor is the support planning at the feasibility stage. If mistakes are made and short cuts taken at this point, the long-term effect can be huge.

- Monitoring systems are vitally important to check the modelling results and to be able to accurately gauge what rock movements the support units are being subjected to.

- When purchasing equipment such as extensometers, if the code of practice (ground control document) requires many readings (4000 per month at Palabora), be careful what unit is purchased. Many units are not capable of this type of usage and will give poor data.

- When designing the support system, time is important since it may be necessary to develop support components, in conjunction with support suppliers, that currently may not exist.

- Support units must be able to accommodate the ground movements that the mining system is going to generate.

- Modern mines cannot be expected to allocate production time to retro-fitting of support. Do not allow the idea “we will come back later and catch that back up” to even be thought, let alone voiced.
• Mining at an average of 34000 tpd can be done with the correct support design and installation. Zero rock related injuries have occurred in the last two years at Palabora. The last injury recorded occurred when a contracts manager barred a piece of rock onto his foot in 2004.

![Rock related Injuries Rate per 1000 per annum](image)

• Finally, as intimated earlier, the support should be designed for the mine’s life, to perform as required and to be practical, and still, very importantly, at the best cost.