



Cave management at Finsch Mine

by C.A. Preece* and B. Liebenberg*

Synopsis

Finsch Diamond Mine, part of De Beers Consolidated Mines (DBCM), is situated between Kimberley and Postmasburg in the Northern Cape, South Africa. The kimberlite pipe was discovered in 1960 and De Beers assumed full mining rights three years later. Production commenced in 1966 from an opencast mine, and the operation moved underground in 1990 by developing and implementing a new mining method of blast hole open stoping. A mechanized block cave was brought into production in 2005.

While block caving was not new to DBCM, with productive caves having operated in Kimberley and Cullinan, from the outset, the Finsch caving operation was designed as the most advanced with a semi-automated ground handling system. The extraction level was laid out as a single sided herringbone system due to the very poor ground conditions on the south side of the pipe. These factors combined to create a unique environment, which necessitated a completely new approach to draw control. The required system was developed by a team consisting of DBCM personnel from head office and Finsch, GEMCOM and Sandvik-Tamrock, the equipment manufacturers.

It was essential that the system could be run quickly, provide daily updates and issue calls directly to the LHDs. It was also important that the base data were obtained from the resource model, which was to be depleted on a monthly basis, thus forming a close link between mine planning and draw control. A further requirement of the system was that it would form a central database for the extraction operation where all data pertaining to delays and changes in conditions, be they production or ground condition related, could be recorded and analysed.

The design brought together empirical rules and tables developed at Cullinan plus concepts from programming developed for the front cave at Koffiefontein so that the new system was based on sound practical experience. These facets were incorporated into PCBC (GEMCOM) and CMS and PCS (Sandvik-Tamrock programmes).

The system has now been operational for just under a year and while modifications have had to be made, it has proved itself as a practical and reliable tool with which to manage the draw control at Finsch. The system is unforgiving and has forced the production team to focus on the specified drawpoints. Problems have been encountered but most of these have been related to re-educating a workforce, familiar with a flexible mining method, to the strict discipline required for a modern block cave.

Introduction

Finsch Mine is located on the Ghaap Plateau some 170 km west of Kimberley in South Africa's Northern Cape Province. The kimberlite orebody is a near vertical sided (76°–84°) and intruded into the Ghaap Dolomite and Asbestos Hills formations of the Campbell Rand Supergroup. Karroo sediments and lavas were present at the time of eruption, as proved by their fragmented inclusions within the kimberlite. De Beers started mining operations at Finsch in the mid 1960s and production moved underground in September 1990. This first phase of underground mining saw a modified blast hole open stoping system extracting the remnants of Block 1 and 2 (Figure 2). This followed an innovative extension of the open pit by benching into the pit, thus gaining revenue at a reduced cost. Block 3, which was brought into production in 1996, again employed open stoping.

Due to concerns over sidewall instability and the potential impact of a massive failure on the operation, it was decided in 1994 to change Block 4 from open stoping to a block cave. Given the late implementation date, it was accepted from the start that Block 4 would not be an optimal cave as it would have to fit within the existing infrastructure as there was insufficient time to deepen the shaft. It was possible to gain a few metres by dropping the extraction level from 59 to 63 Level.

Cave layout

The cave layout chosen was a single sided herringbone (Figure 3) due to the south-west precursor complex, which creates an unstable zone on the south side of the pipe. Thus all tipping takes place on the north side of the pipe. The undercut (61 Level) was initiated in

* De Beers Finsch Mine.

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Figure 1—Location of Finsch Mine within South Africa

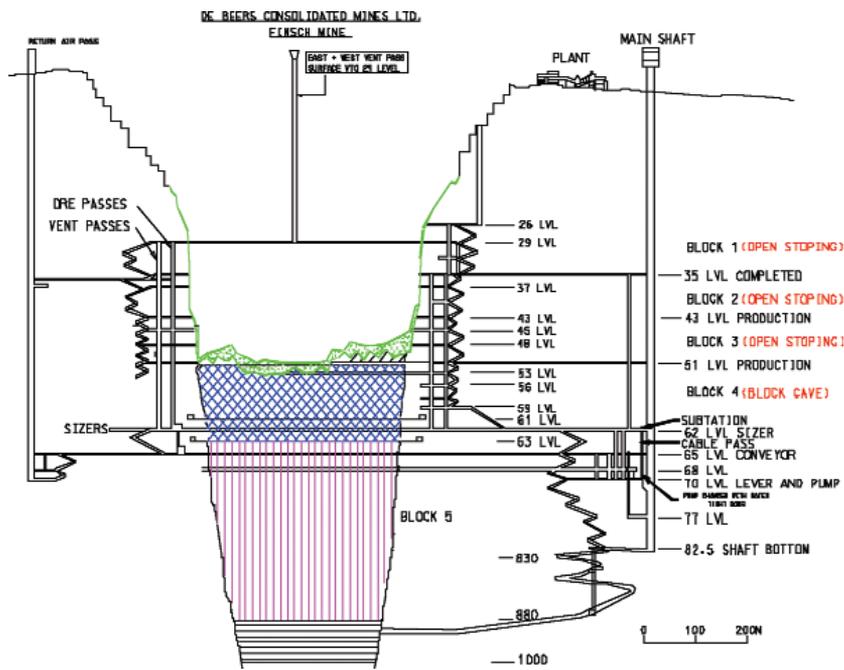


Figure 2—Section through Finsch Mine showing mining blocks

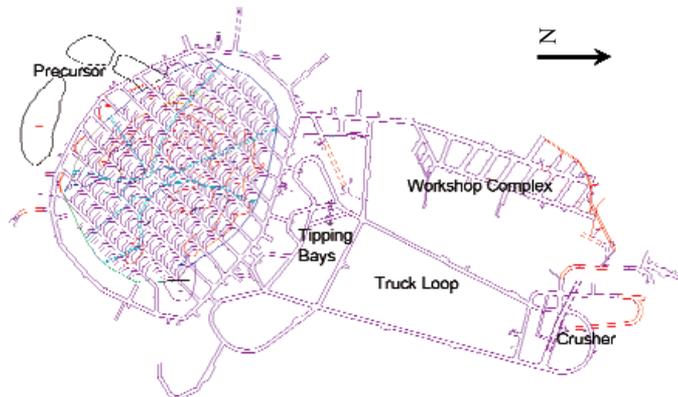


Figure 3—Layout of 63 Extraction Level with outline geology

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the south-east, progressing to the north-west (Figure 4). Numerical modelling indicated this was the best option for induced stresses in the unstable south-west precursor zone. This orientation also allowed the early extraction of the F8 volcanoclastic kimberlite, the richest facies at Finsch, thus significantly improving the economics of the project. Only the drifts were developed pre-undercut due to the low strength of the kimberlite. Once a drawpoint location was overcut and distressed, development and construction took place. Since production commenced in 2004 this work has been undertaken from the south side so as not to hamper production.

The cave was designed to be technically advanced though utilizing proven technology. The LHDs to date have been manually operated and tip into the allocated automated 40 ton dump trucks; these run in a dedicated trucking loop to a gyratory crusher, located close to the shaft. The trucks are controlled via PCS, which is interlinked to the draw control system.

With such an ore transport system there is very limited storage capability before the crusher and any breakdown at the crusher or within the trucking loop very quickly affects production. Typically a 10-minute stoppage incurs a 4-hour recovery time.

For any block cave draw control is the key to success. If draw from the cave is not managed, many problems are encountered, including rat holing, premature waste ingress and recompaction, which can lead to tunnel collapse.

De Beers has been running block caves at Kimberley and Cullinan since the early 1900s and front cave at Koffiefontein prior to its sale in 2006, with mixed success. Finsch, with the limited block height, could not afford any errors. Consequently, extensive research was conducted in the field of draw control, both within and outside of the company.

It was decided at an early stage that Finsch would adopt a semi-autonomous system to work alongside the proposed automated trucks and LHDs. The backbone of the system would be provided by PCBC, with this being translated into the daily call by a cave management system (CMS) and a shift allocation system (PCS). Utilizing PCBC on a monthly basis allows a direct integration of the short and long-term planning, thus simplifying the annual update with monthly depletion.

Experience at Cullinan led to the development of maturity rules for the progressive production build-up from each drawpoint. For Finsch this data were translated into production rate curves (PRC) embedded in PCBC. The PRC are a critical element of the system. If not designed correctly they will result in an undesirably high rate of draw which could cause as many problems as overdraw. The PRC Figure 5 is divided into seven different zones.

The details pertaining to the zones on the PRC are detailed in Table I.

After hydraulic radius was achieved, the original Finsch model called for 400 tons per day (HOD 20 m) to be drawn in zone 1. This resulted in rat-holing to surface, due to the limited block height, and allowed the early ingress of external waste. Due to the well jointed and well bedded nature of the dolomite host rock surrounding the pipe, any waste rock failure from the sides of the pit breaks up into small blocks. This flows preferentially to the coarser kimberlite and was

seen as a serious problem. This led to a revision of the targets and the implementation of the current PRC and a review of the scheduling for the north-west area of the pipe, Figure 6, where draw bell interaction had the potential to be limited and rat-holing a possibility. The plan that was implemented was to return to the pre-hydraulic radius rules. This limited the PRC to a maximum of 50 tons per day per drawpoint until a cluster of 9 drawpoints 4 on either side of a specific drawpoint had reached stage 5 of the PRC. This resulted in both draw and caving continuing in a smooth manner; see also Figure 11.

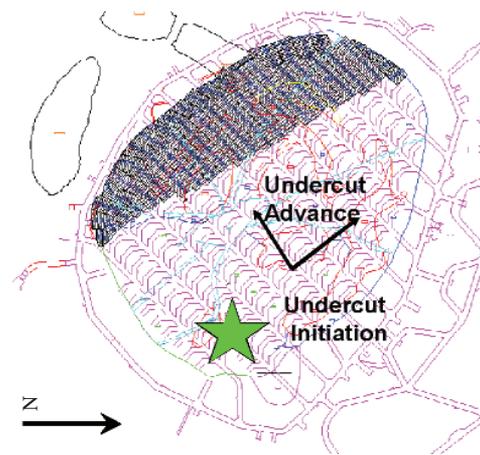


Figure 4—Undercut superimposed on extraction level

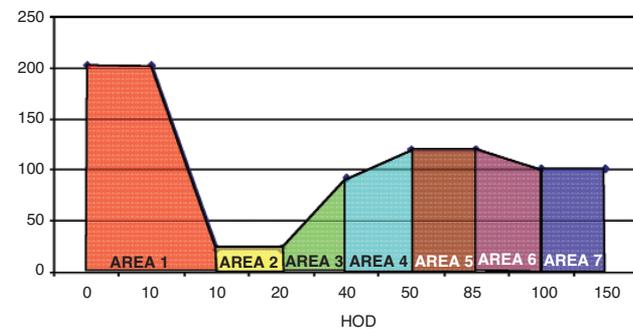


Figure 5—Typical PRC

Zone	HOD (m)	Tons/day	Comments
1	10	200	This area equates to the period when the drawbell is blasted (trough opening)
2	20	20	Cave development
3	20-40	20-90	Cave development
4	40-50	90-120	Gradual ramp-up to ensure free caving occurs
5	50-85	120	Full production
6	85-100	100	Coarse fragmentation expected
7	>100	100	Due to potentially coarse fragmentation and possibly higher than desirable waste ingress

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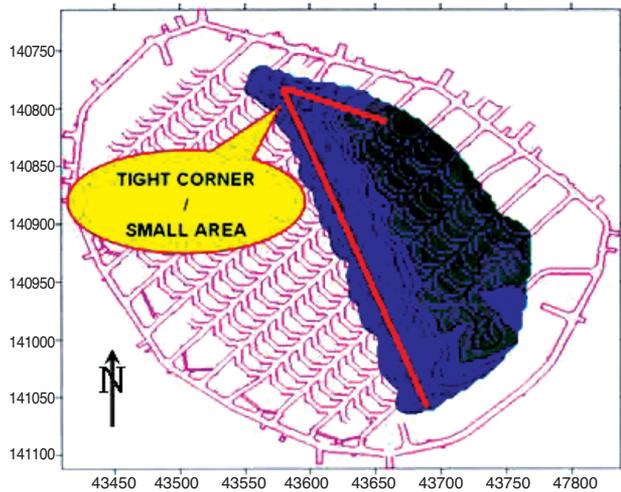


Figure 6—Plan showing potential problem area in the north-west of the pipe

Draw control in practice

Planning and scheduling

The current system at Finsch (Figure 7) starts on the first day of the new production year with the month 1 PCBC run, which is based on the annual GEMCOM block model. The system is specifically configured for Finsch, which aims to maintain the cave within the following limits:

- ▶ The cave ground will form a surface lying at 10°
- ▶ The maximum production from a drawpoint, once mature, would be 120 tons plus a catch-up for any under drawn up to a maximum of 20% (143 tons)
- ▶ The draw will be evenly spread across the block progressing from the south-east to the north-west.

The output from PCBC is then downloaded into CMS, which generates the daily call. This in turn is downloaded to PCS. In the production control room a surface operational control room supervisor (SOC) is on duty for each shift. The PCS system, which controls the LHDs and trucks, continually keeps the SOC on duty apprised of all factors influencing the

operation, e.g. drawpoints hung up since the previous run, breakdowns, etc. With this knowledge and the data downloaded from CMS, the SOC is able to produce a shift schedule. This can be modified throughout the shift as new data (hang-ups, breakdowns, cleared hang-ups) are obtained to ensure optimum extraction. The subsequent shifts are managed in the same way. Data are fed back to the live database in PCS throughout the day, ensuring all relevant production details are fully recorded. Once a day, at about 6 a.m. at Finsch, this data are uploaded to CMS prior to the next production run.

Any underdraw for a drawpoint from day 1 is redistributed over the remaining days left in the month, effectively increasing the daily draw for the affected drawpoint; the same applies to all subsequent days. These tons are known as extras and provide some flexibility within the production section, but the aim is to achieve the required production from each drawpoint within the given month. The process detailed above is repeated daily throughout the month. Overdraw on a small scale does occur, due to bucket loads not necessarily matching the allocated draw. The automated system will not reallocate an LHD until the loading target is achieved. Major overdraw would be possible only if both the SOCS and LHD operators ignored all the visual and audible warnings, and to date this has not happened.

At the end of the month, all data related to ore extraction are downloaded to PCBC. This includes any tons that the production team failed to extract. The system is then run for month 2. The PCBC system is configured so that any drawpoints underdrawn the previous month are subjected to a higher call than their surrounding drawpoints, the following month, so that in the long term the PRC is adhered to. Then again, this data are transferred to CMS and in turn PCS. The sequence then follows that outlined for month 1. The repetitive cycle continues throughout the year until the end of month 12. At this stage a full reconciliation of the depletion of the orebody is undertaken, the GEMCOM block model updated, and PCBC run for the first month of the new year.

Although the system is semiautomated, the draw control mine overseer has manual overrides so that any unforeseen problems can be catered for. An example of this would be the early ingress of waste part way through the month. In this

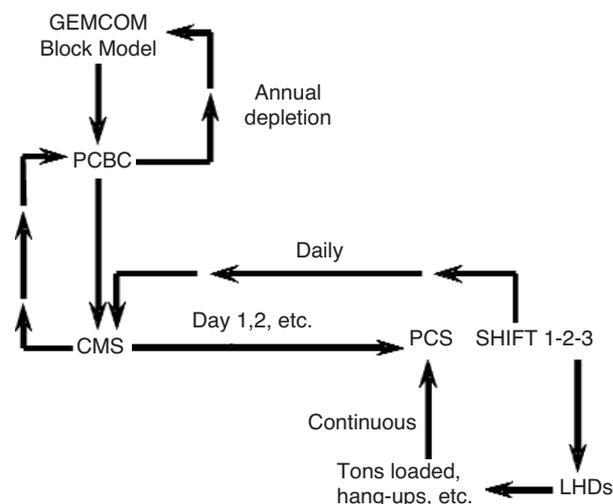


Figure 7—Schematic layout of the integrated draw control system at Finsch

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instance, the call from the affected drawpoints would be manually reduced in CMS. If the problem persists, then in the next PCBC run the maximum allowable tonnage per drawpoint would be reduced.

It was found that the shape of the pipe in conjunction with the orientation of the undercut advance was leading to potential problems. Consequently, both the undercut and the draw control regime had to be modified from that originally planned. However, the PCBC/CMS/PCS combination allowed this work to be adequately planned, scheduled and monitored closely.

Management and review

While planning and implementation of the draw control plan is the primary focus of both the systems and the draw control team, data collection and analysis are also vital activities. All the data that go through CMS and PCS are written to a sequel database. To supplement this information, visual inspections of all drawpoints are conducted each day; the data recorded are:

- drawpoint status
- drawpoint condition
- Fragmentation estimate
- Ore: waste ratio
- Water content.

All the data are analysed in order to confirm good management of the cave. The requirements of this are:

- That the production target was reached
- That extraction complied with the plan
- That waste ingress was not excessive

- That the height of draw displays a constant and progressive increase.

Traditionally the draw control factor (DCF) and production factor (PF) (van Hout 2006) were used to measure the compliance of the ore extraction by the production team. At a very early stage it was recognized that DCF and PF (Figure 8) would not be a realistic measure of compliance to the plan due to the impact of the ground-handling system. As already stated, any breakdown in the truck loop or at the crusher rapidly affected production loading. At the start of the operation, the ground handling system was plagued with numerous small problems. Consequently, it was decided that an alternative measure of compliance was required for draw control that would reflect fairly on the production team.

This factor had to simply measure loading against plan. Having reviewed many options, it was decided to use a monthly weighted average of tons versus target. During the first year of operation, the compliance factor started at 54% and rose to over 70%. During the first five months of 2007 the compliance factor has not fallen below 70% (Figure 9).

Daily reports (Figure 10) are produced advising the production team of the previous day's performance; both successes and problems are high lighted. Each week's achievements are reviewed at the weekly draw control meeting. Much of the success of the operation can be put down to the team co-operation and the desire of the production team to operate the cave responsibly. The start of the production from the block cave initiated a steep learning curve for the mining department, especially the production team. Although block caving has become the internationally

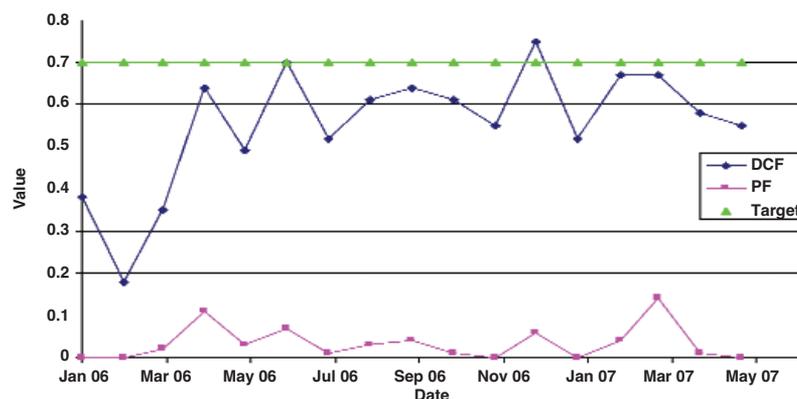


Figure 8—Plot of DCF and PF against target

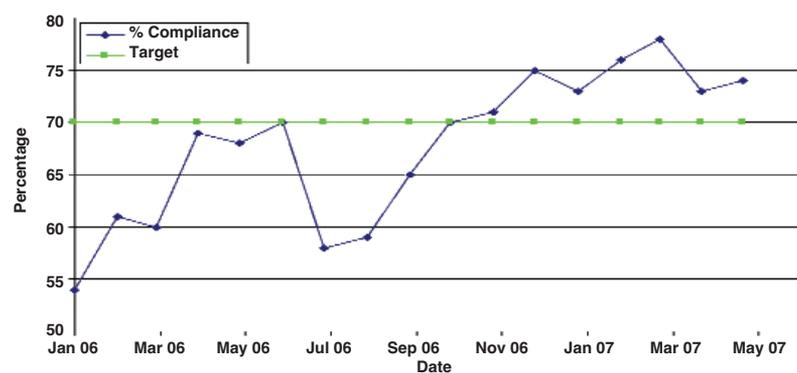


Figure 9—Plot of Finsch compliance factor against target

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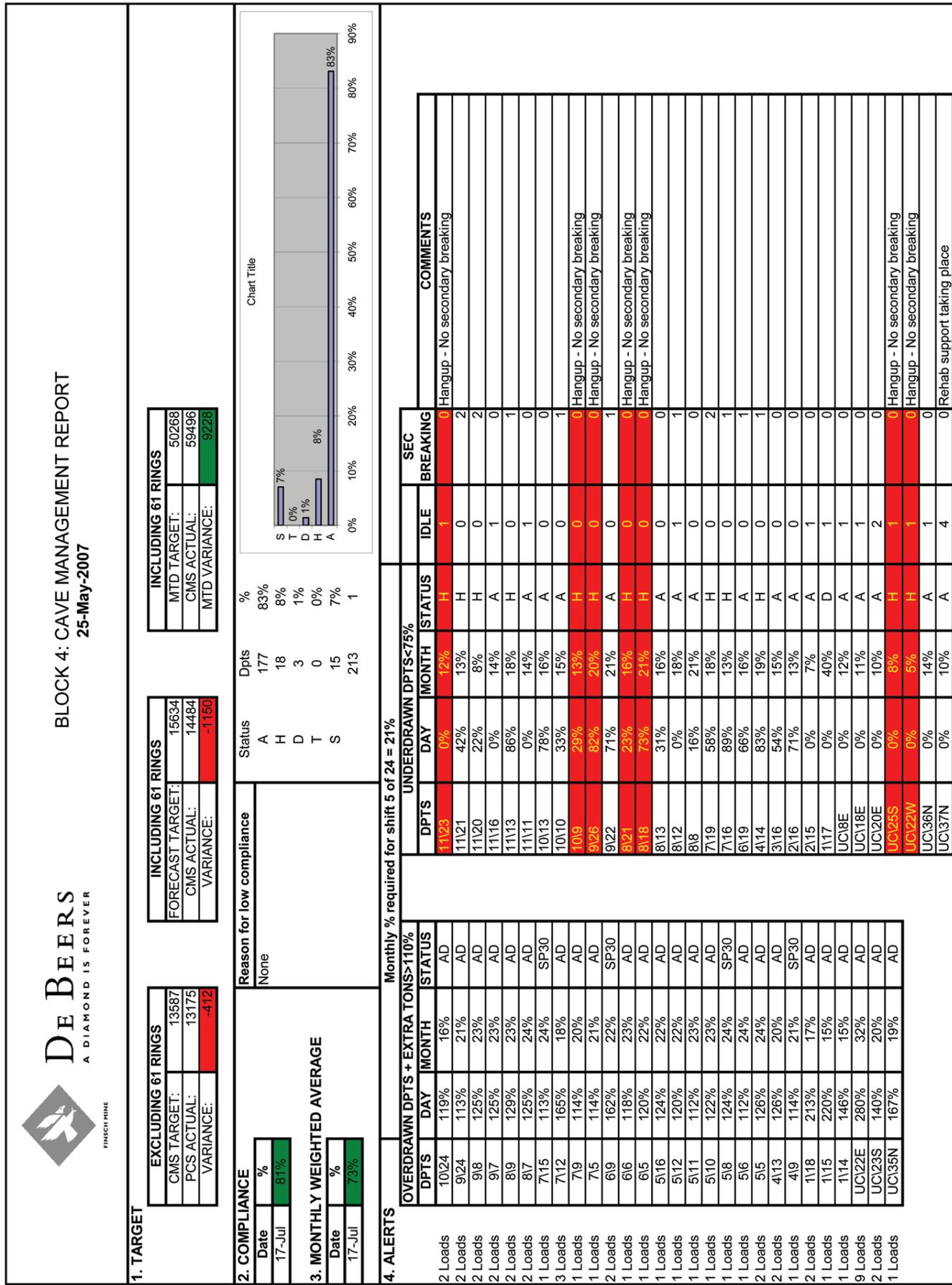


Figure 10—Copy of daily report

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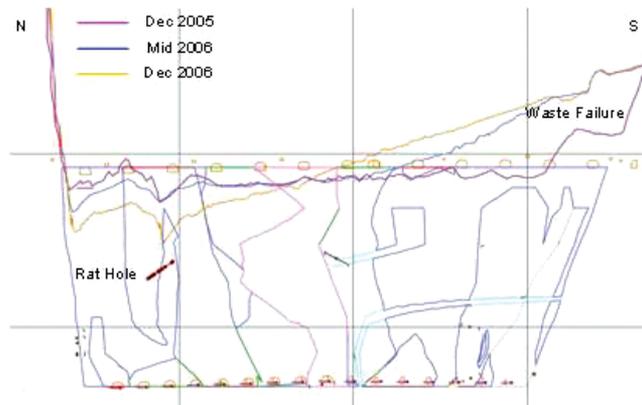


Figure 11—GEMCOM generated section showing ALS profiles with outline geology and drift positions on 53 and 63 Levels

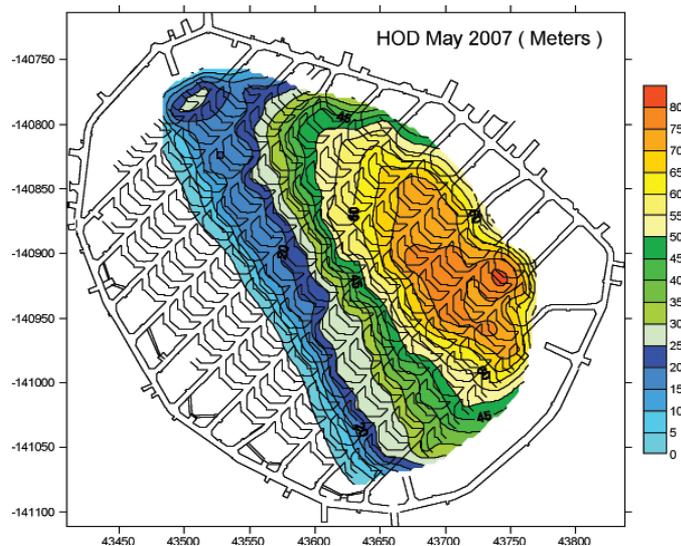


Figure 12—Plot of HOD across the cave to end of May 2007

preferred mass mining method, the limited block height at Finsch means that many of the accepted norms cannot be applied.

Airborne laser surveys (Figure 11) have shown fairly even draw down across the section of the pipe where extraction has taken place. This correlates well with the HOD plots. A problem of early waste ingress can be attributed to excessive (planned) tonnage being drawn in the central area of the pipe during trough opening and rat-holing taking place due to the limited block height. This was exacerbated by the subvertical internal lithological contacts and the slightly differential cave ability characteristics of the basalt breccias and F1 kimberlite in the area.

It is not clear as to whether there will be complete draw column interaction across the pit floor due to the limited block height, however, some interaction is apparent; as indicated by the migration of external waste across the block.

After 18 months of production, the Finsch team are producing 14 500 tons daily from the Block 4 Cave with over 70% compliance to the plan and progressive fairly even draw, Figure 12. Since the original rat-holing and waste ingress further rat-holing has been avoided though external waste has been continued to run at between 2 and 3%, indicating that the original rat hole allowed a considerable volume of

waste to flow into the cave. There is no doubt that without the PCBC/CMS/PCS system a much larger draw control team (currently only 3 people) would have been required, and it is doubtful if the same level of management and control could have been achieved. The Finsch scenario shows that by careful integration of technology and competent personnel, a cave of sub-optimal height can be both productive and well managed.

Acknowledgements

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