Mining an open pit over and through old sub-level caving operations at Kwaggashoek East Open Pit, Thabazimbi Iron Ore Mine

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ABSTRACT

The Kwaggashoek East pit is one of the four production areas of Thabazimbi Iron Ore Mine. The Kwaggashoek East Open pit mines through the abandoned sublevel caving operations of the Kwaggashoek East underground workings. A risk assessment indicated that the primary risk is the occurrence of surface subsidence. Based on local knowledge, a hypothesis, that most of the cavities were filled with broken rock as a result of roof collapse and bulking of failed material was formulated. To test the hypothesis a number of geophysical methods as well as probe drilling was utilized. The results of the resistivity, gravity and ground penetrating radar surveys were inconclusive in determining the position of voids. Either there were no voids present or the resolution of the surveys was not high enough to pick it up. It is accepted that only small voids remained, and that the supported roof hypothesis is valid. As a precautionary measure all the production blast holes within the caving area were over-drilled by forty percent. This would collapse the roof of any small voids or tunnels immediately below the block. This operation proved to be successful as two of the three underground levels have been mined out with no subsidence occurring in the pit floor.

1. INTRODUCTION

Table 1: Production Statistics of Thabazimbi Mine:

Thabazimbi Iron Ore Mine is situated near the town of Thabazimbi in the Limpopo Province, South Africa. The mine has been in production since 1934. The first open pit operations were started in 1956. Until 1998 both open pit and underground-mining operations existed simultaneously in different areas. Underground mining operations were abandoned in 1998 primarily as a result of high mining cost and bad ground conditions. Only, open pit mining is currently conducted. The mine currently has four production areas, Buffelshoek West, Donkerpoort West, Donkerpoort Neck and Kwaggashoek East. The run of mine is 245,000 tonnes per month from which 200,000 tonnes of iron ore product is railed to Mittal Steel plants at Vanderbijlpark and Newcastle. The average stripping ratio for all the pits is 12:1. The current life of mine is 4 years. The Kwaggashoek East Open Pit plays a strategic role in the rest of Thabazimbi Mine’s life.
2. GEOLOGICAL SETTING

The mine produces high-grade hematite ore from the supergene enriched Penge Formation of the Chuniespoort Group of the Transvaal Sequence. Different structural events caused over-thrusting and consequent triplication of the Transvaal Sequence rocks in the area. The geological strata strike approximately east west and dip approximately 40 degrees to the south. The dolomites of the Malmani Subgroup usually occur on the northern slopes of the ridges with the Banded Iron Formation at the top and on the southern slope, the shale and quartzite of the Rooihoogte and Timeball Hill Formations outcrop further to the south in the valley. The supergene enriched hematite ore bodies occur in a highly altered basal portion of the Penge Formation, overlying a shale unit and occasionally underlie a diabase sill. The shale unit and the diabase intrusions can be classified as difficult strata due to weak rock properties. The combination of collapse structures into the underlying dolomite, faulting and folding has led to a highly complex and altered geological environment, Van Deventer (1986).

3. KWAGGASHOEK EAST MINING AREA

Sub level block caving operations started in 1990 with the extension of infrastructure from the East Mine operations 4 kilometers west of Kwaggashoek East. Production started in October 1994 on the 510° level (1366 level). Operations were terminated in 1996, on the 540 level (1336 level). A total of 396 000 tones iron ore was extracted from three levels of the eastern spiral, which is only 8 percent of the total reserve of 4.9 Mt.

Figure 1 Layout of Kwaggashoek Open Pit with underground infrastructure indicated

*The 510 level refer to the Mine’s local Coordinate system used for all underground operations. All Open pit operations are referenced to the LO 27 Coordinate system, relative to mean sea level
Although the western spiral has been developed, no caving was done there. Refer to Figure 1 for an overview of the underground layout relative to the designed final open pit.

Kwaggashoek East Open Pit:

- Total resource 9.377M t
- Total minable reserve 4.92Mt.
- Pre Stripping started in 2002
- Ore production started May 2004
- Current Life of Pit - 4 years

4. OCCURRENCES OF SURFACE SUBSIDENCE.

The following occurrences of surface subsidence were recorded since underground production ceased in 1998:

- Surface subsidence occurred in 1998 on the mountain slope above the 510 level caving area
- Surface subsidence was observed on 14 January 2002 on the 1430 level after blasting a nearby block.
- A small ‘sinkhole’ occurred on the 1390 level after the area was ripped by D10 bulldozer, preparing the bench after blasting. 17 April 2004 (Photo 1). The position of this structure was above an intersection of tunnels on the 1366 level (510 level)
- A surface depression was noted on 20 May 2004 in the muck pile after a block was blasted also on the 1390 level. (Photo 2) This feature was located close to the south-eastern edge of the caving area.
- Small depression was observed on the muck pile after a blast on the 1380 level on 26 July 2004. First block blasted using over drill (Photo 4)
- The Kwaggashoek East Pit is currently (December 2005) being mined on the 1350 level.
Apart from the small collapse structure or sinkhole that occurred on the 1390 level when it was prepared for drilling, no other subsidence features were noted or recorded prior to blasting on the levels.

5. RISK ASSESSMENT

A Fault-tree based risk assessment was conducted. The impact of “sinkhole” type structures, surface subsidence and the effect of overcharging blast-holes were evaluated. The assessment indicated that the formation of surface subsidence features on the production level scored the highest risk rating.

6. HYPOTHESIS FORMULATION

Based on local knowledge the “supported roof” hypothesis was proposed. The hypothesis assumes that caving would have continued after the workings were abandoned. The caving process will continue to a point where either surface subsidence will occur, or where the caved material would have filled the void to such an extent that the roof was largely supported by the caved material and the caving process is halted. Subsequently there will only remain small voids along the edges of the caved area. This hypothesis is based on the fact that the extraction ratios from the draw points were fairly low, (40 percent on average) and that the caving levels were fairly close to surface (50-80m). This means that approximately 60 percent of the blasted material was left behind. If the bulking factor of 50 percent due to blasting is added, it is safe to assume that only about 15 percent of the blasted cavity is unfilled. This translates to a total volume if approximately 13 000 cubic meters of void space over an area of 21 000 square meters. This translates to an average void ratio of 0.61. Further caving would have occurred over time and surface subsidence was reported prior to the start of open pit mining, further reducing this volume of voids.
7. HYPOTHESIS TESTING

Probe drilling, electrical resistivity, gravimetric survey and ground penetrating radar methods were evaluated to determine the suitability of each in delineating the boundaries of possible voids.

8. DISCUSSION OF FIELDWORK RESULTS

8.1 Geophysical Methods

The Electrical Resistivity Tomography (ERT) survey resulted in a model of the electrical resistance vertically along the survey line. The depth to which anomalies can be detected is a function of the line length and the resolution is a function of the length of the probe spacing.

The vertical resolution of the survey at Kwaggashoek was limited to approximately 5m along the east west-lines where a 10m probe spacing was used and 3m along line 3 where a 5m spacing was used. Thus, for the ERT method to be effective, to “see” at least 30m deep at a resolution of 3m, the layout should consist of a line at least 300m long with an electrode spacing of 3 m.

The gravity technique is not sensitive enough to register cavities that are small and tabular in shape. Also, the low density anomalies can be masked by the heavy iron-rich rock mass.

Both the resistivity and gravity surveys indicated low density or high resistivity anomalies in the same areas, which correlates well with the positions within the caving area where extensive caving (on all three levels in the same area) was done.

The Ground Penetrating Radar (GPR) survey did not perform as expected. From the results, it is clear that GPR is not applicable at Thabazimbi Mine. Due to the conductive nature of the banded ironstone formations the radar energy is “absorbed” by the rock mass, resulting in a weak return signal.

The highly conductive nature of the rock mass indicates that the resistivity method could be the most applicable method to determine the existence of voids accurately because it functions best in highly conductive materials. Given the pit layout, it is however difficult to establish a 300m flat area in an operating pit only 350m long.

Smaller anomalies of less than 8 cubic meters, such as those shown in photo 1 were not identified by the gravity, although it was situated within the survey area and less
than 10 m below the surface. The ERT method would have been able to identify this type of anomaly if the survey line crossed over it.

The geophysical methods used were also unable to identify any structures that were larger than 27 cubic meters. These structures do however exist as seen from the subsidence structures observed on the muck piles (photo 2). It should be noted that this feature was the only one observed and it was positioned close to the south eastern edge of the caving area.

The results of the geophysical surveys substantiate the conclusions made by Jaing et al (2003) that “geophysical tools has not yet proven to be a practical alternative” to probe drilling.

### 8.2. Probe Drilling

The probe drilling on the 1400 level was done on a 30m by 30m grid covering the whole caving area with 60m deep holes. On the 1390 level the process was repeated with the grid offset so that the 1390 to 1340 level was covered by a 15m by 15m grid.

The driller was instructed to record penetration rate, drilling conditions, air-loss as well as occurrences and depth of cavities. The results obtained from the probe drilling did not intersect any cavities, but air-loss and caving in of holes did occur above the caving zone.

![Figure 2: Layout of probe holes relative to current pit floor on 1360 level.](image-url)
On the 1380 level (14m) above the upper caving level, 18 meter deep probe holes were drilled at the intersections of haulages and cross-cuts. The size of the tunnels was 3m by 3m. Substantial air loss and cavities were recorded in 30% of the holes drilled.

9. MINING THROUGH THE 510 LEVEL

As per the mine’s Code of Practice all geotechnically unstable or potentially dangerous areas are classified as Special Areas. The Kwaggashoek East Caving Special Area was declared a limited access area in January 2002. Access to the area was limited to production equipment only. No equipment was to be parked in the area. Drilling was done using smaller truck mounted percussion drill rigs with the compressors parked outside the special area, rather than the large rotary rigs used elsewhere. As far as practically possible all haulage roads were diverted around the caving area. No loading was done in the special area after dark.

From the 1380 level downwards all production blast holes within the caving area were drilled 14m deep. (10m bench plus 2m sub-drill and an additional 2m over-drill. The whole 14 m bench was then blasted and only the top 10 meters mined out. The decision to over-drill the production blast-holes was based on the size of the draw points and the calculated stable span based on the rock mass classification. The blast would punch through the roof of any structure less than 18 below the surface. This ensured a safe zone of 8 meters thick on the haulage level.

From Photo 3 it is evident that this procedure is capable of collapsing near surface structures on the 1380 level. Photo 4 was taken from the 1360 level. The split-sets, wire-mesh and shotcrete of the 510 level draw points are clearly visible about 3m from the top of the muckpile.
10. CONCLUSIONS

The results indicate that the “supported roof” hypothesis is valid. The risk analysis indicated that the primary risk to equipment is as a result of surface subsidence and not sudden collapse. The inability to intersect or indicate underground voids within the caving area with remote methods does not mean that they do not exist, it is more likely that the sample spacing was too coarse. Geophysical methods did not produce the required results. The Special Area Procedures that are in place are adequate to ensure the safe mining of the caving area. Accurate survey information of the positions of old workings is invaluable.

The only viable method of cavity identification is probe drilling and accurate drillers logs. The density of the probe drilling grid depends on the size of the structure that is targeted. Since the majority of the probe holes intersect the ore zone the geology department log and sample the percussion chips from the probe holes. This added benefit increase the value of the probe holes to more than just cavity probe holes.

The over-drill method was very successful to create a safe mining level. In environments where the vertical extent or span of cavities is larger, the over-drill should be increased to at least half of the stable span.
10. REFERENCES & BIBLIOGRAPHY
