



Project report—pillar mining at No. 1 and 2 sub-shaft on Kloof Gold Mine

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Paper written on project work carried out in partial fulfilment of
BSc Engineering (Mining)

Synopsis

The aim of this project is to determine whether certain pillars occurring within the no. 1 shaft and no. 2 sub-shaft ground are feasible for extraction. The extraction of these pillars is essential in prolonging the life of Kloof Main Shaft as its VCR resource becomes depleted. Extraction of these pillars will require a combination of designs and factors, with rock mechanics and ventilation being the main considerations.

Primarily for the pillar extraction, an initial production target of 150 kg gold, mineable in one year from commencement of 'opening up' was set. The planned target has been exceeded and the feasible pillars identified are expected to yield an additional 1 390 kg of gold to the shaft's production profile.

However, not all the required ventilation designs have been completed to date, the reason being that at the time of the project, many of the pillar areas were inaccessible and thus ventilation conditions are unknown. This project is therefore an ongoing process and will require further design once all targeted pillar areas have been opened up.

A preliminary costing analysis of the pillar mining was performed and it was found that all targeted pillars with the exception of 38–61 pillar are profitable.

Mining in the Division primarily involves extraction on the Ventersdorp Contact Reef (VCR). Other reefs exploited are the Middevelei Reef (MR), Kloof Reef (KR) and the Libanon Reef (LR). Upon inception of Kloof Gold Mine in 1968, a mining lease was granted at depths of between 2 500 and 3 700 metres down dip of the Libanon mine. Since the establishment of the first shaft at Venterspost in 1934, mining within this area has produced more than 65 million ounces of gold.

Geology

The orebody is situated on the West Wits line, between the north-south trending Witpoortjie Fault to the east and the Bank Fault to the west. Within Kloof's boundary, the VCR is most prominent and the mining area extends for 27.5 km on strike and 7.5 km on dip. Minor production is, however, also planned on the other reef horizons. Figure 2 is a geological section illustrating the layout of the above-mentioned orebody⁵.

Mining at Main Shaft occurs at depths ranging from 2 000m down to a depth of 3 500m. Pillars in the 1# zone range from 2 km to 2.5 km in depth, while those in the 2 sub# zone range from 2.5 km to 3.5 km in depth.

Project background and objectives

The Kloof orebody has for many years been a consistently good producer of gold, with mined ore running at average grades of 13.5 g/t between 1968 and 1994. However, there has been a trend of declining gold grade in recent years, as well as gold price. A probable cause for this trend could be that there has been an increase in production from the lower grade Middevelei Reef package, while mining on the VCR has decreased due to depletion of the resource. Gold grades now average 7.3 g/t and

Introduction

Mine background and general information

Location

Located in the world-renowned Witwatersrand Basin, some 60 km south-west of Johannesburg near the town of Carletonville in Gauteng, Kloof Gold Mine is part of the Kloof Division. The Kloof Division, which is found to the east of the Driefontein Division, includes the former Venterspost (10#), Libanon (8#, 9#), Leeudoorn (7#) and Kloof Gold Mine (1#, 2#, 3#, 4#) and was created by a merger in 1992⁵. The Kloof Division is one of three South African operations within the Gold Fields group. The shafts on which the project work was carried out, no. 1 and no. 2 sub, are known as the Main Shaft complex and can be seen in Figure 1.

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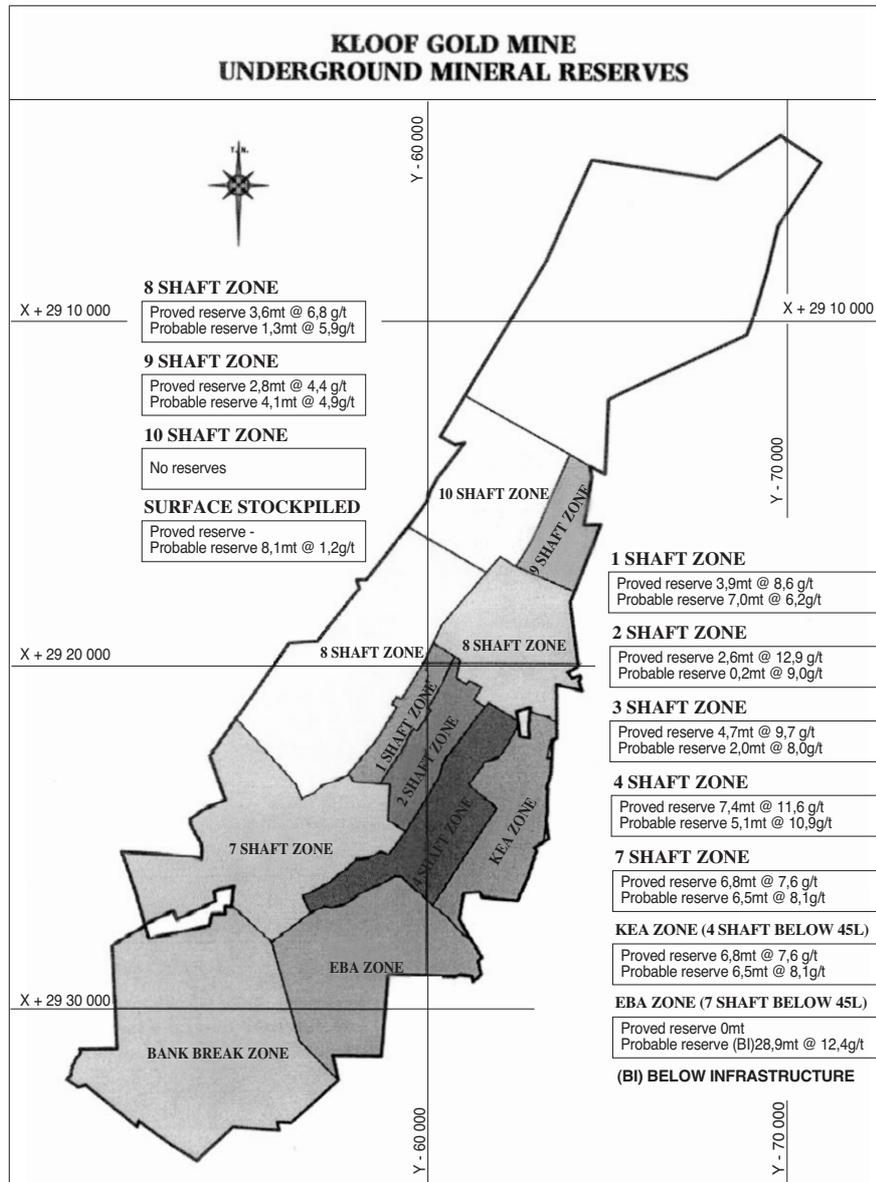


Figure 1—Site plan and mineral reserves⁵

this, coupled with a lower gold price, has had a negative effect on the profit margins of many gold mining companies. The consequences in some instances are dire and result in losses and even possible closure for some of the higher cost producers, such as Kloof Main #. It is for this reason that alternative measures need to be considered so as to render gold mining more profitable for investors.

The first of these measures would be to increase production so as to attain more gold. This unfortunately is very difficult to obtain in an industry that utilizes manual labour extensively, and unless mechanization becomes the main mining force, these greater production demands will not be met with ease. The second alternative, however, is to look for high-grade areas and, where possible, extract them so as to enrich the ore going to the metallurgical plants. This will then result in a higher average grade ore and hence lower the costs of mining and processing the ore that has come from areas of depleted grade.

The main objective of this project is therefore to consider

the mining of high-grade pillars, which have been left *in situ* over the years, and assess them individually for safe extraction. It will therefore be necessary to take into account rock mechanics and ventilation restrictions while mining is in progress. A sufficient number of pillars will be assessed so as to meet the production requirement of increasing Kloof Division's production profile by 150 kg of gold in one year. The main objectives identified are as follows:

- Identification of pillars in collaboration with Valuation and production personnel
- Feasibility study on the identified pillars
- Demarcation of ground to be left *in situ*, so as to serve as regional pillar support for the immediate mining area
- Planning of the mining sequence and subsequent numerical modelling of the sequence for each pillar using the software package, MinSim 2000
- Required development and 'opening up' schedule in order to gain access to pillar ground

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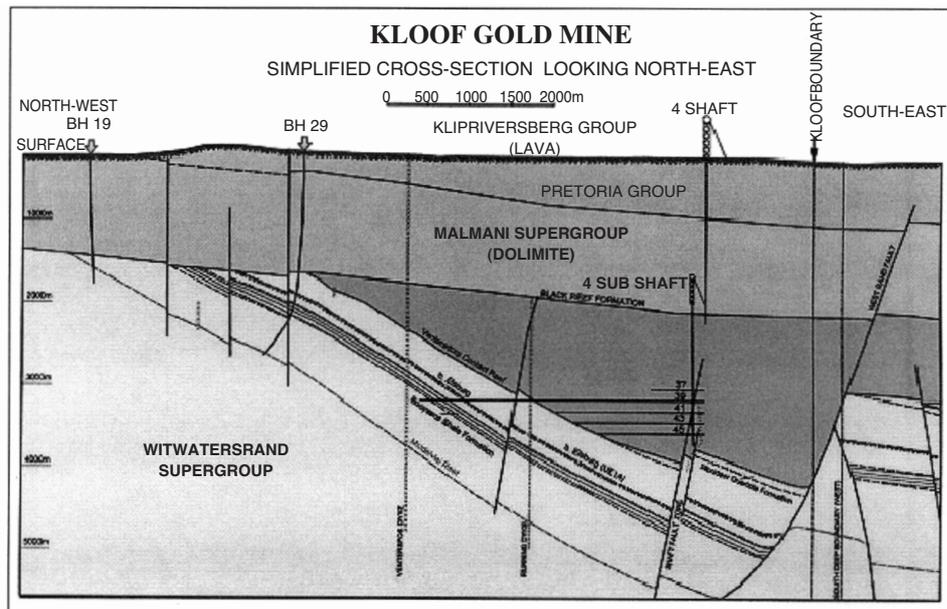


Figure 2—Geological section showing reef horizons⁵

- Secondary support requirements to be decided upon and ventilation layouts to be designed for the respective pillars
- Calculation of mineable ground and predicted revenue to be generated from pillar extraction
- Scheduling of the whole process in order to manage and monitor progress of the pillar extraction.

Problem statement

The purpose of this research is to investigate certain pillars for extraction. The identification of pillars for extraction must therefore result from a combined effort of the production personnel and other departments directly involved with the extraction—the rock mechanics, geology, ventilation and ore valuation departments. Each pillar will therefore be individually investigated so as to ascertain the ventilation requirements, rock mechanics restrictions, support requirements, as well as services required. Once all this information has been obtained, costing analysis will be done on the respective pillars to determine the profit or loss that can be expected from each pillar.

Scope of the study

A number of objectives have been identified for this project as seen above. It must be noted, however, that the main concern in pillar extraction is the safety of the workforce, working within what will become a so-called remnant area or special area. Therefore, proper rock mechanics planning and analysis are required before any other mining plans can proceed. This project will therefore focus more on the Rock mechanics-related aspects of pillar extraction. These will include numerical modelling of the pillars in order to determine the most suitable mining sequence as well as the influence of extraction on footwall stresses. It must be further noted that mining is to take place on pillars outside of the shaft area and that mining of the shaft pillar itself will not be taking place at this stage.

Literature review

Much has been published to date about the extraction of shaft pillars, strike stabilizing pillars and smaller irregular pillars, and it was therefore decided to review the most current practices and design strategies for removing pillars.

Jager and Ryder¹, discuss various design strategies for mining at deep and ultra, deep depths; these strategies include:

- The use of regional support in the form of stabilizing pillars
- Control of energy release rate
- Use of bracket pillars along geological structures (i.e. faults and dykes)
- Controlled leads and lags along stope faces
- The use of rapid yielding support in areas of high seismic risk
- Development performed in a de-stressed environment

It is then also realized that the structure of the rock mass and the conditions of the discontinuities will govern the extent of instability around an excavation and consequently the choice of support system. With regards to seismicity, it was noted that in South African deep-level gold mines, the rockburst damage to excavations is generally due to seismic events occurring on major mining abutments or fault/dyke structures. Jager and Ryder², then go on to discuss the required design criterion for stable pillar extraction and it is noted that for foundation failure of a pillar to be avoided, the UCS should not be exceeded by 2.5 times its strength.

Lougher⁴, describes the post-peak behaviour of pillars and it is found that the behaviour can be described as being 'yielding without shedding load'. From his studies, it was discovered that a 'plastic' behaviour of pillar failure is experienced, with the yielding mechanism being, footwall punching of the pillar. It is therefore realized that the design of remaining stabilizing pillars in this project need to be adequately designed so as to avoid foundation failure. This is

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vitaly important as some of the pillars planned for extraction are linked to strike stabilizing pillars connecting the shaft pillar, and failure would result in shaft stability problems. Finally, York³, looked at the possibility of replacing pillars with concrete as support. This alternative will not be considered, however, due to the high cost associated with concrete fill support systems.

Numerical modelling of pillars

Method selection

Numerical models for solving arbitrarily shaped tabular voids (i.e. stopes and geological discontinuities) in an elastic medium are based on so-called boundary element analysis models, also called the displacement discontinuity method. The method is capable of modelling complicated planar geometry whilst assuming that rock behaviour is of an isotropic elastic nature. Analysis of stresses and strains is therefore only solved for on the boundaries of the excavation under inspection and this simplifies the modelling as opposed to using finite element methods. A limiting factor of this method, however, is the fact that modelling of inelastic rock mass behaviour is not well suited and therefore other methods for the modelling of heterogeneous mediums need to be used. The modelling package that was used for the purposes of modelling the pillars is MinSim2000. This package is capable of analysing how stresses are redistributed around a mining horizon and takes account of important factors such as average pillar stress (APS) levels as well as excess shear stress levels (ESS) occurring within pillars and along geological discontinuities.

Design criteria

It was initially decided that the numerical modelling be used to test proposed design specifications against recommended design criteria as published in the Code of Practice to combat Rockfall and Rockburst accidents on Kloof. The first design criterion was to ensure that the pillar extraction sequence did not result in an average pillar stresses above 2.5 times the uniaxial compressive strength of the reef horizon (i.e. VCR). In order to achieve this design criterion, various mining extraction layouts are sequenced and the lowest stress resulting layout is selected. The second design aspect taken into account is the excess shear stress (ESS) estimated on the planes of weakness (i.e. dykes and faults). The magnitude of a seismic event is then estimated and a design value of 2 for the event is set as the ceiling limit value for the expected event. Should the estimated magnitude of the event, calculated from the ESS, exceed 2 on the Richter scale, the mining extraction sequence will have to be revised.

Average pillar stress

The average pillar stress criterion is basic to designing and assessing the magnitude of stress build-up in and around the boundaries of pillars. The average pillar stress is an indicative criterion for the worst-case stress scenario in the immediate mining environment around the pillar. These stress values can then be used in order to determine the following:

- Whether stabilizing pillars are likely to fail by foundation failure

- Whether a pillar is likely to fail by other means as a result of stress exceeding the uniaxial compressive strength of the rock mass.

In order to prevent failure of the bracket and stabilizing pillars, a conservative criterion of $APS < 2.5 \sigma_c$ (quartzite) was proposed². All modelling was done to ensure that this design consideration is not exceeded.

Excess shear stress

Numerous statistical and seismological studies have confirmed that mining in the vicinity of geological structures, such as faults and dykes, greatly increases the incidence of seismic events and accompanying rockbursts¹. It is therefore necessary to account for the excess shear stress that is likely to be encountered on the geological discontinuities in and around the pillars left during mining.

A plane of weakness, such as a fault, will be subjected to induced shear stresses as a result of mining. It is the build-up of the induced shear stress that eventually exceeds the shear strength on the plane and results in a seismic event. The ESS therefore measures the effective driving force on the plane that might lead to the onset of a dynamic event.

Modelled pillars

All pillars that were modelled using MinSim 2000 have not been included in this section of the report. Rather, one pillar namely 38-61 has been selected in order to illustrate the extraction and modelling process followed. It must be noted, however, that every pillar had unique design factors to consider due to the varying geology as well as depth of mining. A particular example of this is where in some of the pillar designs, varying hangingwall conditions had to be accounted for due to a weaker lava formation known as the Westonaria Formation (UCS 120 MPa). In other cases the much stronger Alberton Lava Formation (UCS 200 MPa) was encountered and this brought about differing design considerations.

38-61 Pillar

Situated in the no. 2 sub-shaft area, the 38-61 pillar is positioned between a dyke on the northern side and the so-called Whitey's Fault. The fault has a 30 m downthrow of the reef plane and dips at 110° in an easterly direction while running from the 53 line through to the 61 line. Seismic activity along the fault has occurred in the past with the largest event being recorded at a magnitude of 2.5 on the Richter scale. It is for this reason that a 20 m bracket pillar has been left along the length of the fault so as to improve stability. In addition to the bracket pillar along the fault, a second bracket pillar 10 m thick will be left along the dyke plane intersecting the fault.

It is envisaged that mining will proceed first to the corner of the fault/dyke intersection so as to mine with lower induced stresses. From the modelling done it was noted that the highest peak stress encountered within the pillar is ± 310 MPa. This occurs along the dyke plane and therefore verifies the necessity of the bracket pillar left *in situ*. The APS for the remaining pillar as can be seen in Figure 3 is 118 MPa, which is well within the stress threshold limit.

The presence of Whitey's Fault, which is seismically active, necessitates further analysis of ESS expected on the

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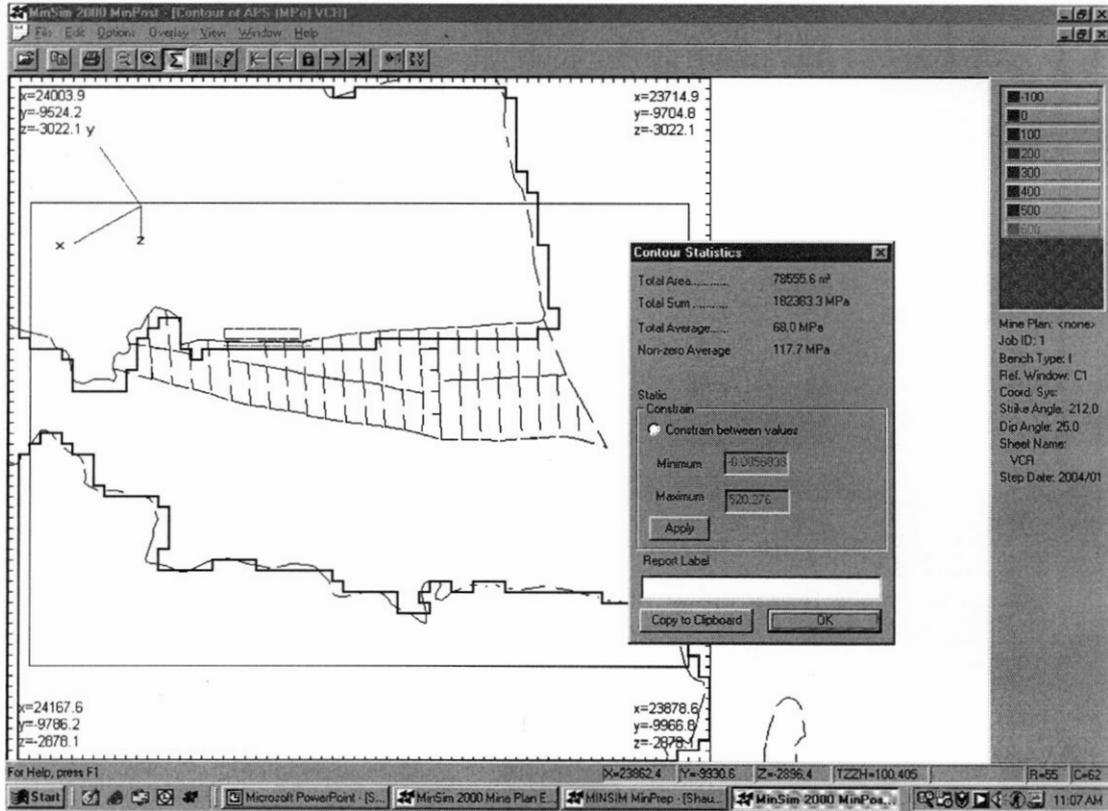


Figure 3—Diagram indicating stress distribution and APS value of the 38-61 pillar

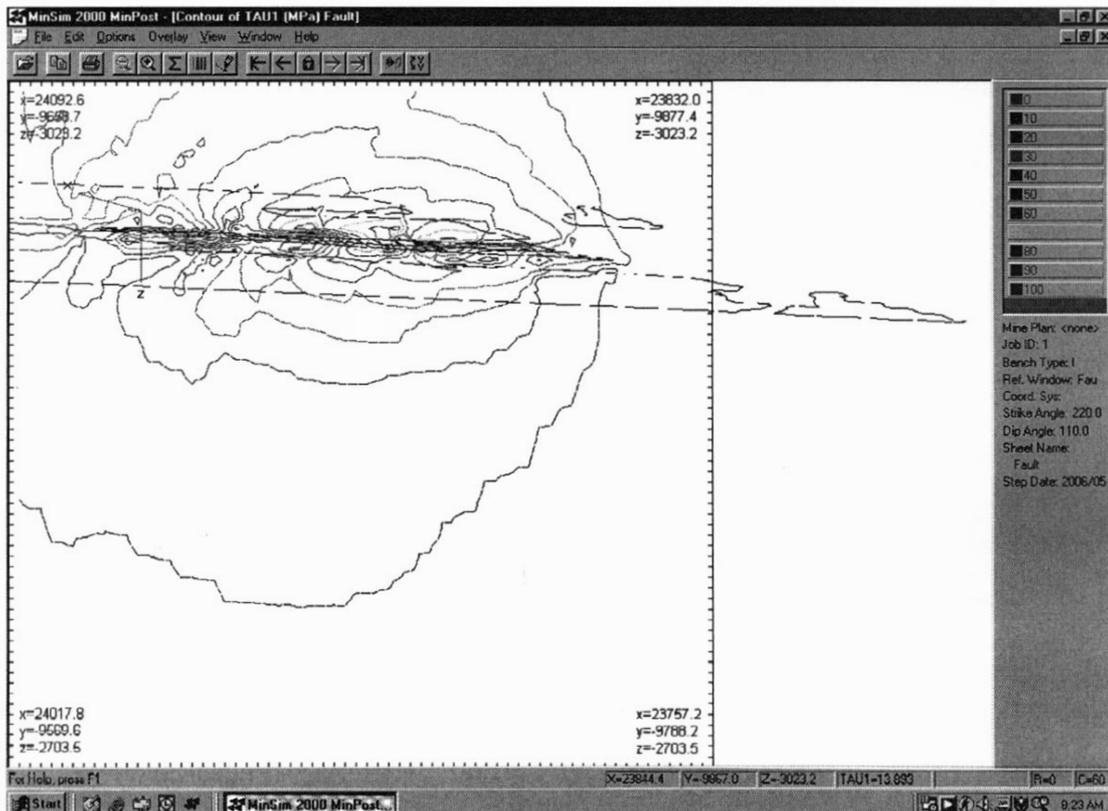


Figure 4—Off-reef sheet of Whitey's Fault and associated stress lobes for 38-61 pillar

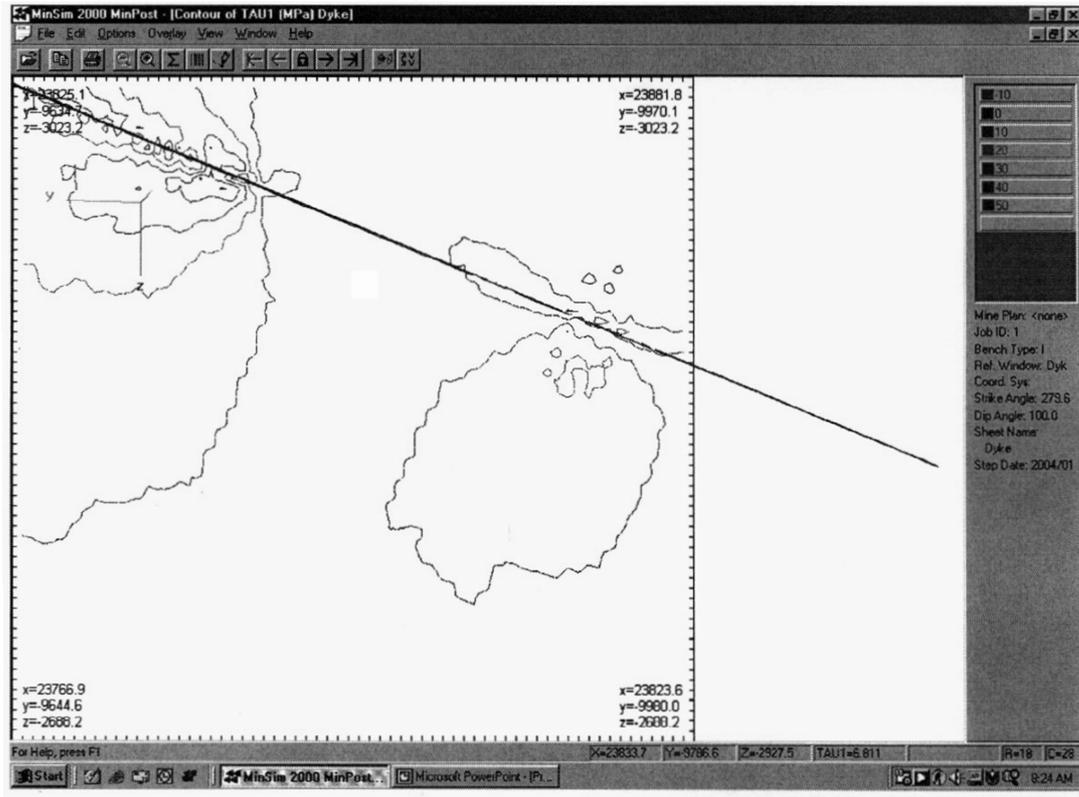


Figure 5—Off-reef sheet of the dyke plane and associated stress lobes for 38-61 pillar

plane of weakness. The same holds true for the dyke and therefore Figures 4 and 5 and calculations below aim to indicate expected magnitude of events that will occur on the geological structures.

The moment and magnitude of Whitey's Fault are:
Moment²

$$\begin{aligned}
 Mo &= 2 Te A^2 L \\
 &= 2 \times (50\text{MPa}) \times (9.376 \text{ m})^2 \times (86.853 \text{ m}) \quad [1] \\
 &= \underline{76\,3519.3034 \text{ MN.m}}
 \end{aligned}$$

∴ Magnitude²

$$\begin{aligned}
 Mag &= \log (Mo) - 3.1/1.5 \\
 &= \log (763519.3034) - 3.1/1.5 \quad [2] \\
 &= \underline{1.855}
 \end{aligned}$$

Moment:

$$\begin{aligned}
 Mo &= 2 Te A^2 L \\
 &= 2 \times (30 \text{ MPa}) \times (0.79755 \text{ m})^2 \times (14.256 \text{ m}) \quad [3] \\
 &= \underline{544.08 \text{ MN.m}}
 \end{aligned}$$

The moment and magnitude of the dyke are:

∴ Magnitude:

$$\begin{aligned}
 Mag &= \log (Mo) - 3.1/1.5 \\
 &= \log (544.08) - 3.1/1.5 \quad [4] \\
 &= \underline{0.669}
 \end{aligned}$$

From the above calculations it can be seen that the theoretical values estimated for the event magnitudes fall below the threshold value of $ML < 2$. However, it must be

noted that it was assumed that the energy of all previous mining was dissipated through previous seismicity. A further restraint of these estimations is the fact that no link between theoretical and actual event magnitudes has been ascertained and this therefore indicates that even bigger events may be expected along these geological discontinuities.

Ventilation requirements

Apart from the necessity to perform numerical modelling on the pillars for them to be extracted in the safest manner, it becomes necessary to ensure the provision of ventilation within the pillar areas. High temperatures in excess of 32°C are usually encountered in the pillar areas and it is very important that the ventilation conditions within the working stopes of the pillar areas meet mine health and safety policies.

The layouts for provision of ventilation onto the working faces have been drawn up with the assistance of the ventilation department. However, not all the layouts have been drawn up to date, the main reason being that pillar reconnaissance is necessary so as to ascertain ventilation conditions. Furthermore, not all the pillars have been 'opened up' to date and therefore the reconnaissance process has not been completed. Once temperatures have been recorded, it then becomes possible to calculate the required air volume to be delivered to the face as well as the amount of refrigeration necessary to maintain legal ventilation temperatures. The current ventilation standard for a working stope face air velocity is to be no less than 0.25 m/s and the maximum wet bulb temperature must not exceed 32.5°C (Mine Health and

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Safety Act of 1996). All ventilation planning was therefore centred on these standards, so as to meet them and where possible ventilation conditions were even further improved. Shown here are the calculations performed for the 38-50 pillar area. A similar approach was adopted for the other pillar areas where pillar reconnaissance was carried out.

38-50 Pillar

The pillar is situated in No. 2 sub-shaft's ground at a depth of ±3.2 km and therefore the virgin rock temperature has a huge role to play in prevailing ventilation conditions. Due to the high air temperatures recorded in this area, it was realized early on that additional cooling was required in the form of a bulk air cooling car. The ventilating air will be drawn from 38 level and down the 36-50 cross-cut. From here it will enter the south reef drive and traverse up through the workings. All return air will be exhausted out through the 37-50 cross-cut and back to the No. 2 ventilation shaft. As the bracket pillar left in the dyke/worked out area

intersection, will also serve to prevent ventilation loss into the 'old workings' (see Figure 6 below).

The calculations illustrating the amount of refrigerating power required are shown below.

From a pillar reconnaissance performed, the various ventilation parameters were recorded:

- Wet bulb temp. 33°C
- Dry bulb temp. 35°C
- Barometric pressure 116.25 kPa
- Virgin rock temp. 46.6°C

∴ Design requirements:

- Wet bulb 28°C
- Air volume 10 m³/s

Thus, the change in depth from stope entrance to stope exit is as follows:

$$\begin{aligned} \Delta H &= -3102.580 \text{ m} - (-3040.808 \text{ m}) \\ &= \underline{61.772 \text{ m}} \end{aligned} \quad [5]$$

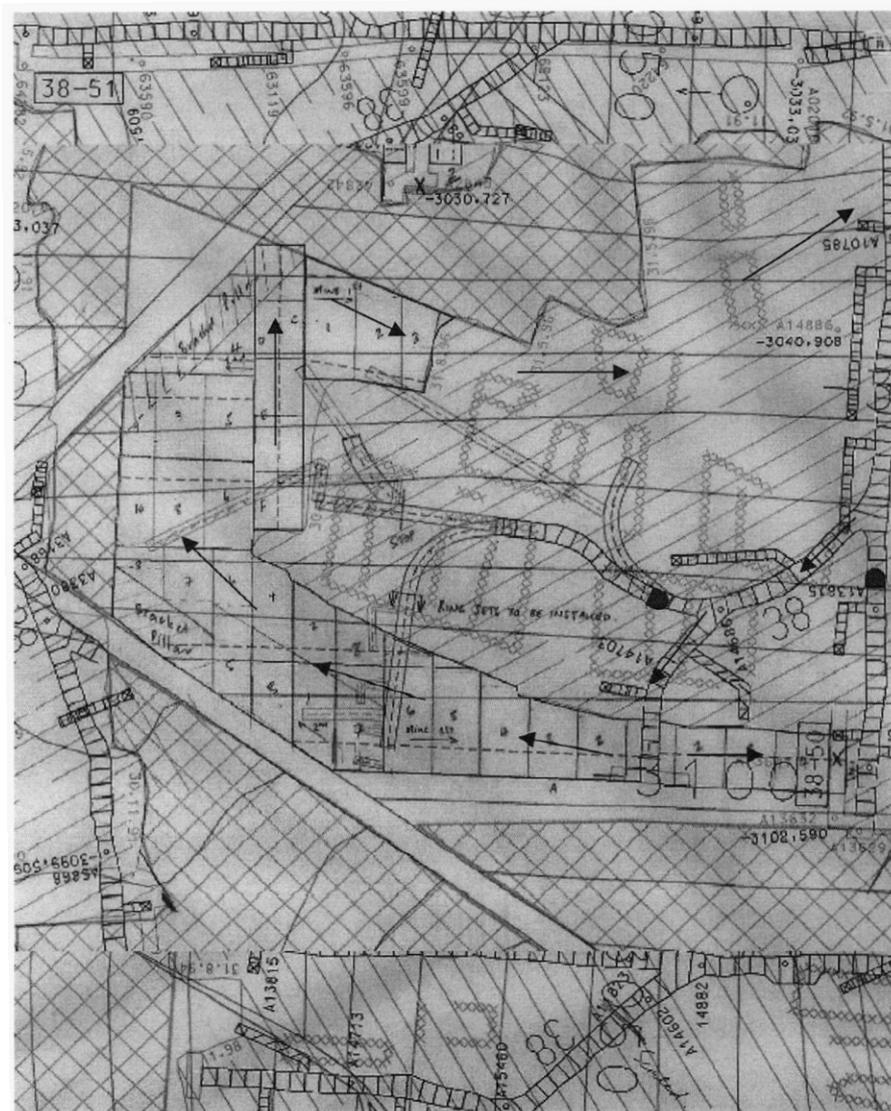


Figure 6—Plan showing ventilation layout for 38-50 pillar

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∴ Using 117.5 kPa psychometric chart

$$r = 27 \text{ g/kg}$$

$$V = 0.786 \text{ m}^3/\text{kg}$$

$$S = 100.50 \text{ kJ/kg}$$

∴ Mass flow rate.

$$= Q/V$$

$$= 10 \text{ m}^3 \cdot \text{s}^{-1} / 0.786 \text{ m}^3 \cdot \text{kg}^{-1} \quad [6]$$

$$= \underline{12.72 \text{ kg/s}}$$

Therefore using values from above, the heat exchange can be calculated as follows:

$$\Delta S = S_{\text{Before}} - S_{\text{After}} \quad [7]$$

$$= 100.50 \text{ kJ/kg} - 67 \text{ kJ/kg}$$

$$= \underline{33.5 \text{ kJ/kg}}$$

The net heat transfer rate required is therefore as follows:

$$q = m \times \Delta S$$

$$= 12.72 \text{ kg/s} \times 33.5 \text{ kJ/kg} \quad [8]$$

$$= \underline{426.12 \text{ kJ/s}}$$

∴ Installation of a 500 kW bulk cooler will provide a suitable working environment.

Pillar costing

The ultimate goal of any mining project is to derive a profit from the venture under investigation. The financial feasibility component of this project is therefore an important factor, to determine whether to go ahead with the extraction of the above-mentioned pillars or not. It is therefore essential to perform a costing analysis of the mining on the pillars planned for extraction. A costing analysis of the pillars was thus performed, which involved only the direct mining costs associated with the extraction of the respective pillars. The reason for only performing direct costing is due to the complexity associated with incorporating fixed costs that the mine incurs into the analysis. Each pillar was treated uniquely as the 'opening-up' costs varied with differing geological conditions. Table I illustrates the total gold content from all the mineable ground.

In order to obtain the total gold content mineable from the pillars, all plans were measured and scaled to size, so as to attain the areas illustrated in Table I. The average grade as stated has already been evaluated and a semi-variogram

model applied, so as to account for the lognormal nature of the orebody. The actual modelling and geostatistical analysis was performed by the ore valuation department on Kloof Mine and all values stated are assumed to be correct. The total gold content is a reduced value as a result of the shaft's average mine call factor (MCF) of 90%, as well as the plants extraction factor of 98% being applied. A summary illustrating the costs associated with each pillar is shown in Table II.

Using a gold price of R85 000/kg (2003/12), the following gross profits were estimated. It must be noted that the costing performed on these pillars is of a direct nature and was performed for the purposes of a prefeasibility study on these pillars for extraction. Therefore, no discounted cash flows have been considered over the duration of the pillar extractions. The profits/losses are shown in Table III.

All pillars with the exception of 38-61 could therefore be extracted at a profit when using the above costing criterion. The main reason for the unprofitability of the pillar is the low grade experienced within the area. Further prospect drilling and sampling are therefore required in order to make a proper assessment of the pillars viability. The pillar should only be removed if its extraction falls in line with the ore valuation department's plans for ore blending, which in this case is 30% unpay and 70% payable ore mined.

Pillar scheduling

The aim of this section is to illustrate the exact period of time required for each pillar to be 'opened up' and then subsequently extracted in the planned sequence as determined during the numerical modelling stage of the project. The scheduling for the pillars was performed using, MicroSoft Project 2000 and a schedule for each shaft and its associated pillars was drawn up accordingly. A summary graph illustrating the extraction period for all the modeled pillars is shown in Figure 7.

As can be seen from the graph, the gold production is a ramp-up process and increases in line with increased extraction rates. Once all the pillars have been mined the total gold added to the production profile of Kloof Main #, will be in the order of just less than 1 400 kg. It is also assumed here that the 38-61 pillar, previously identified as being unprofitable, will be extracted along with the other pillars. The extraction of this so-called 'unpay' ground will contribute to 6.5% of the gold production profile and therefore falls in line with the unpay/pay ratio of 30%/70%.

Table I

Gold content for pillars

Pillar	Area (m ²)	Channel width (m)	Tonnage (t)	Grade (g/t)	Gold content (kg)
24-38	2105	1.35	7672.73	24.50	165.80
29-55	2275	1.37	8415.23	14.81	109.92
35-34	2574	1.52	10563.70	28.50	265.54
38-50	4778	1.43	18447.86	47.00	764.74
38-61	4770	1.40	18030.60	5.34	84.92
				Total gold	1390.92

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Table II

Summary table of direct pillar mining cost

Pillar no.	Development (rands)	Stoping (rands)	Rehabilitation (rand)	Reasons
24-38	10 000	5 831 275	121 500	Dev: 2 m @ R5 000/m Stop: 7 673 t @ R760/t Rehab: wire/mesh and lacing 90 m @ R3 000/m
29-55	125 000	6 395 575	183 600	Dev: 25 m @ R5 000/m Stop: 8415 t @ R760/t Rehab: wire/mesh and lacing 68 m @ R2 700/m
35-34	0	8 028 412	183 600	Stop: 1 0564 t @ R760/t Rehab: wire/mesh and lacing 61 m @ R3 000/m
38-50	1 218 662	14 020 480	884 300	Dev: 229 m @ R5 000/m Stop: 18 448 t @ R760/t Rehab: wire/mesh and lacing 229 m @ R2 700/m Ring sets 38 m @ R7 000/m
38-61	1 186 293	13 703 256	731 100	Dev: 223 m @ R5 000/m Stop: 18 031 t @ R760/t Rehab: wire/mesh and lacing @ R2 700/m

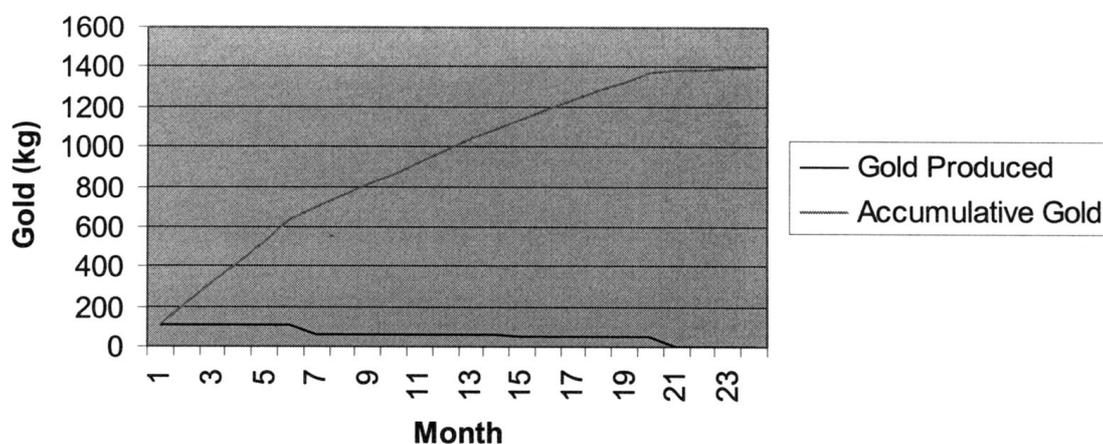


Figure 7—Graph illustrating the accumulative gold planned over the scheduled extraction period

Table III

Summary of profit/losses for pillar extraction

Pillar no.	Profit/loss (rands)
24-38	8 130 225
29-55	2 639 025
35-34	14 358 888
38-50	48 879 458
38-61	-8 402 449

Conclusions

From all the prefeasibility studies performed on the aforementioned pillars, the following conclusions can be drawn:

- All the average pillar stress values attained during numerical modelling of pillars fall within the required design criterion value of 450 MPa. However, high peak stress values of 620 MPa encountered within the 35-34 Pillar area signify a high risk zone with the possibility of strain bursting on the face should mining proceed.

- The estimated seismic event magnitudes for the 38-50 pillar and 38-61 pillar also fall within the design criterion value of magnitude 2 on the Richter scale. A possible alternative solution to reduce the event size of 1.94 in the 38-50 Pillar area, would be to leave a larger bracket pillar along the dyke. This is due to the fact that alternative extraction sequences were considered but were found to be impractical.
- As mentioned before, not all of the ventilation conditions in the pillar areas were assessed during the time of the project. This was due to some pillar areas being inaccessible and also to lack of earlier ventilation records given the time when certain pillars were last mined. Nevertheless, it was found that for pillar areas: 24-38, 35-34, and 38-50, bulk cooling cars with a power of 500 kW would be required. The use of such cars would in all three areas provide ventilation conditions in line with the Mine Health and Safety Act, which stipulates a maximum wet bulb temperature of 32.5°C. The air velocities will be maintained by making use of 22 kW fans and 760 mm regulators in all of the intake airways.

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For the scheduling of the pillars it can be seen that all of the ground is planned for extraction over a period of some 22 months. Although this is longer than the initial planned time period of one year, it is expected that production targets will still be met. It is expected that the total gross profit to be derived from the extraction of these pillars is in the order of R65 million and hence would increase greatly to the Revenue of Kloof Main # .

Recommendations

Finally, from the prefeasibility studies carried out, it can be seen that all pillars with the exception 38-61 are profitable. It is therefore recommended that the planned extraction of this pillar be aborted, as it will result in a loss of some R8.5 million. The extra capital can rather then be used to 'open up' other high-grade pillars occurring in the No. 1 Shaft area. Of particular interest could be the 29-30 pillar, which if 70% extracted would yield an additional 620 kg of gold at an average grade of 50 g/t. Finally, it is also important to note that pillar mining is a high-risk activity and although risk assessment is something that was not covered in this report, it forms a vital part of the decision when engaging in pillar extraction studies. A last recommendation is that a full risk assessment be conducted on each of the modelled pillars before moving to the next stage of the pillar extraction study.

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