Pushing the Boundaries by Mining Them

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ABSTRACT

The Randfontein Cooke section was and continues to be a very profitable revenue generating mine. It was at the threshold of closing down when Harmony acquired the assets some 10 years ago, and it is still at that threshold. The Cooke 1 section has been kept alive, providing jobs and adding value to the company portfolio because of innovative mining born of necessity
The original design of Cooke 1 mine incorporated a compromised system of regional stability pillars. The compromise entailed leaving typically 10 to 15 m pillars against major structures along their length, and where these were not deemed adequate to support the next region, an attempt was made at creating a systematic grid of pillars.
The challenges faced by the Cooke 1 team was to go and extract these very pillars that were designed to provide regional stability, and any other pillars left in the wake of the high production flagship of JCI.
This paper presents an informal and (perhaps subjective), discussion of how these challenges were met and some of the lessons learnt in the process.

1. INTRODUCTION

1.1. Locality

Harmony Gold Mining Co. Ltd, Randfontein operations comprise four shafts: Cooke 1,Cooke 2 and Cooke 3 shafts and Doornkop shaft. The mine is situated to the north of the Western Areas mine and east of the town Westonarea. It is about 10 km west of Soweto.(Figure 1)

Figure 1: Location of the Harmony Randfontein Operations

1.2. Geological facts

The orebody exploited at Randfontein operations is part of the Witwatersrand supergroup, also known as the Wits Basin.(Figure 2) The mines are situated on the north western limb of the basin.

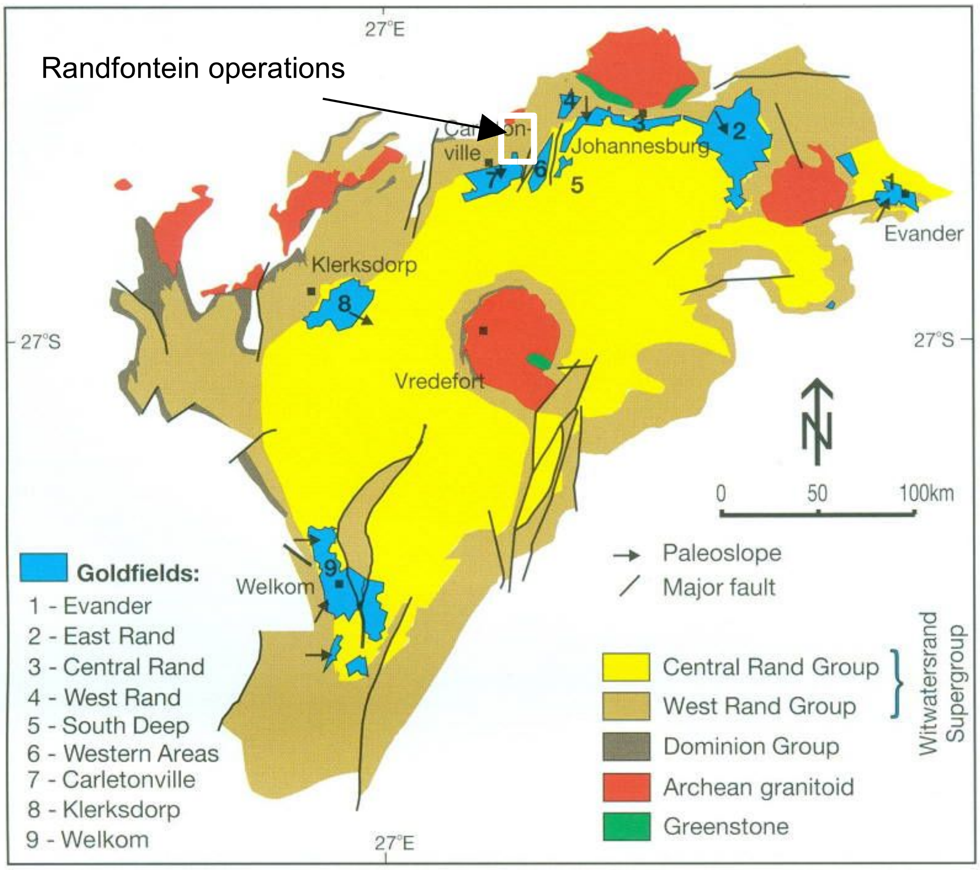

Figure 2: The Witwatersrand Basin

At Cooke 1, the general regional dip direction is southwards, however due to folding the reef contours form a sinuous pattern and the orebody basically takes the form of a basin, or bowl. (Figure 3).

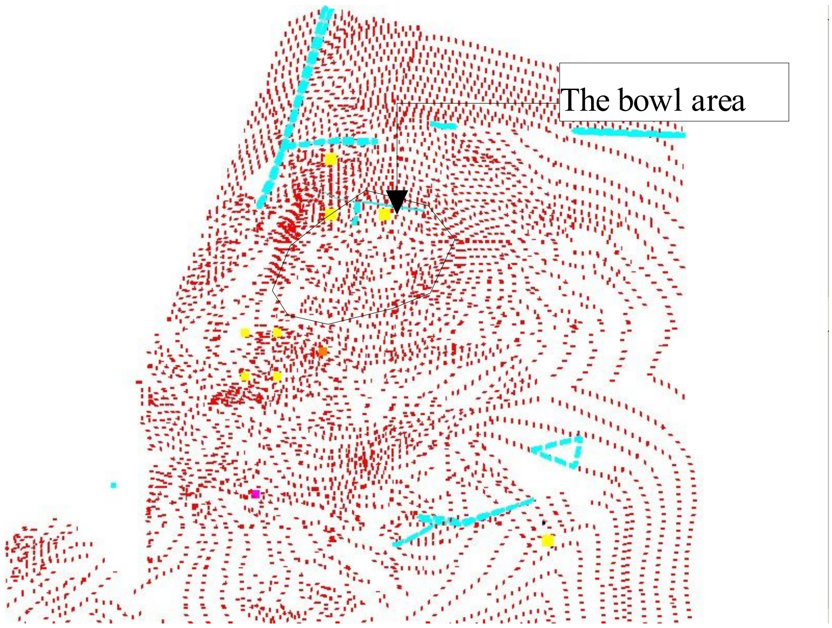

Figure 3: The reef contours of Cooke 1 shaft

Two major fault trends are present. The first set strikes north-north east and the other strikes roughly east-west. The latter faults are often associated with lateral displacements. These faults have a tendency to be water bearing, suggesting that they are of Transvaal age and connected to the dolomites.(Figure 4)

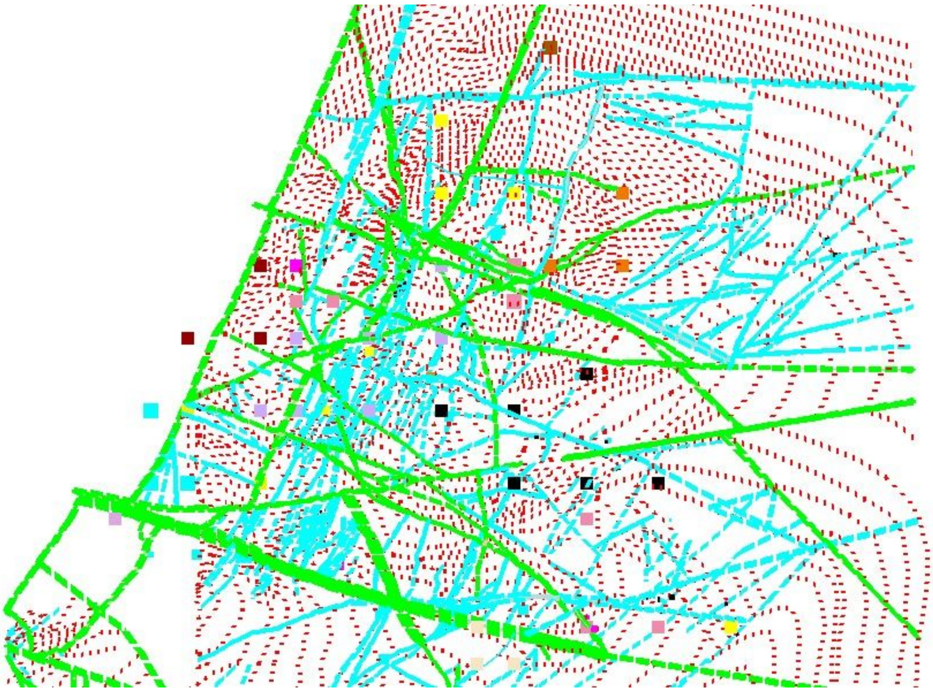

Figure 4: Faults and dykes on Cooke 1

The surface overburden consists of soil, partially decomposed dolomite and leached chert. This covers about 400m of Malmani Dolomites, the first two hundred meters or so of which is oxidised and water bearing. The base of the dolomites consists of a layer of readily decomposable soft shale known locally as the black reef.(Figure 5)

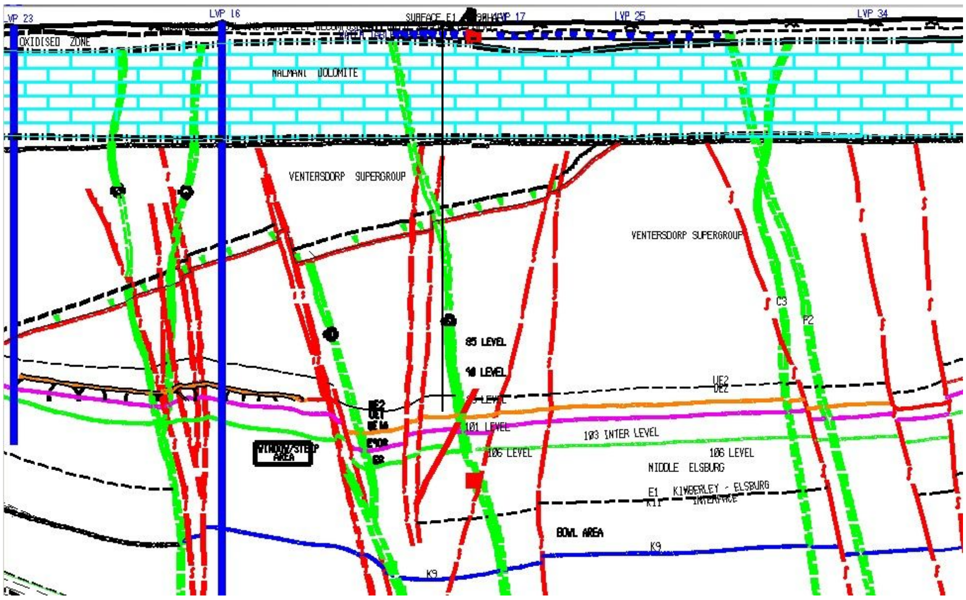

Figure 5: Partial East-West Section of Cooke 1

Below the shales, the geology becomes a bit more complex as the Ventersdorp lava forms a wedge between the shale and the Witwatersrand quartzite. The lava sub out crops unconformably against the black reef and is directly underlain by the Ventersdorp contact reef, a structure formed by reworking of the Witwatersrand conglomerates.

At Cooke 1, the succession containing the economical reefs occurs in the upper Elsburg series of the Turfontein Sub group of the Witwatersrand Super group. As explained earlier, on the western side of the property, the Ventersdorp lava overlies part of the Witwatersrand supergroup unconformably. On the eastern side of the property, the Black reef shales directly overlie the Turfontein sub-group.

1.3. Ore bodies mined

The main economical horizons are situated between 600 and 900 m below surface and comprise the E8 and particularly the UE1A reefs. Occasionally the E9 Grit Bands between the latter two reefs can be extracted economically. The reef dip is normally very gentle at below 15 degrees.

To the west of the mine, near the Ventersdorp lava sub-outcrop, the reefs are closer together and sometimes occur as a single package. The reefs diverge gently towards the east where the middling attains a distance of about 60 m.

The channel width can vary between 4,0 m on the E8 horizon at places and 80cm. The average stope width is 1.5 m.

1.4. Current status of mining project

Cooke 1 shaft is a mature mine, reaching the end of life, in fact the end of life has been extended several times. In about 1999/2000, shaft pillar extraction commenced and was for the major part completed around 2004. Shortly after shaft pillar extraction commenced a programme was embarked upon to identify and mine payable isolated blocks of ground that have been left in situ in the past. For the sake of simplifying discussion, these isolated blocks of ground will, in this paper, be referred to as pillars, regardless of the reason for their existence.

1.5. Financial Information

In the past values in excess of ten thousand cmg/t were not uncommon on Cooke 1. Mining the pillars has yielded an average value of about four thousand cmg/t. The operation has generated substantial annual profits since 2003. In the last year the profit has declined sharply as sustaining the required volumes became increasingly difficult due to almost complete depletion of the ore-body and increasingly deteriorating infrastructure.

1.6. Seismological Information

During and after the shaft pillar extraction, seismic activity increased, and although the seismicity levels had dropped significantly since, they remain relatively high for a shallow mine.(Figure 6)

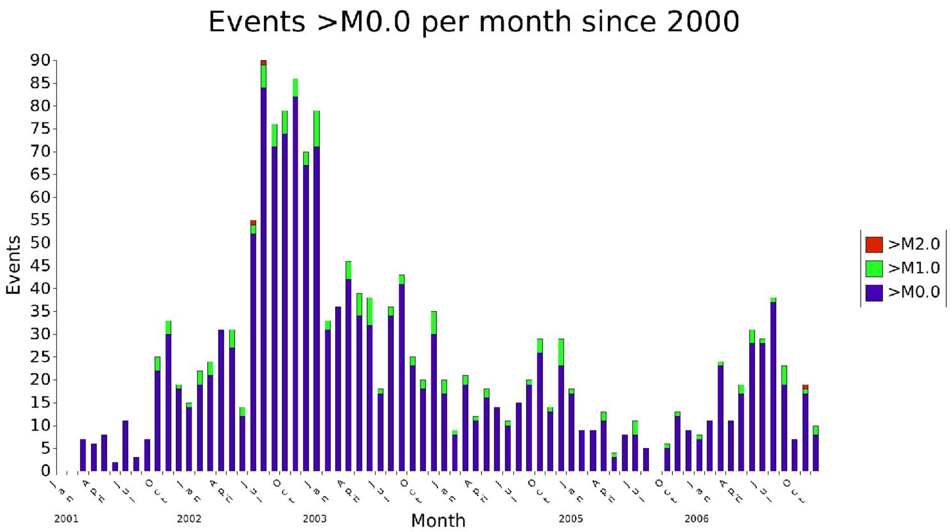

Figure 6: Seismic activity over time at Cooke 1 shaft

The source of the seismicity is believed to be associated with geological structures. It is thought that after removing the shaft pillar, the remaining pillars have softened to such an extent that substantial strain energy can no longer be sustained, and that geological structures now became the primary energy source.

Subsequent data analysis appears to bear out this hypothesis as can be seen from the contour plot (Figure 7) where contours of high apparent stress correspond to structures.

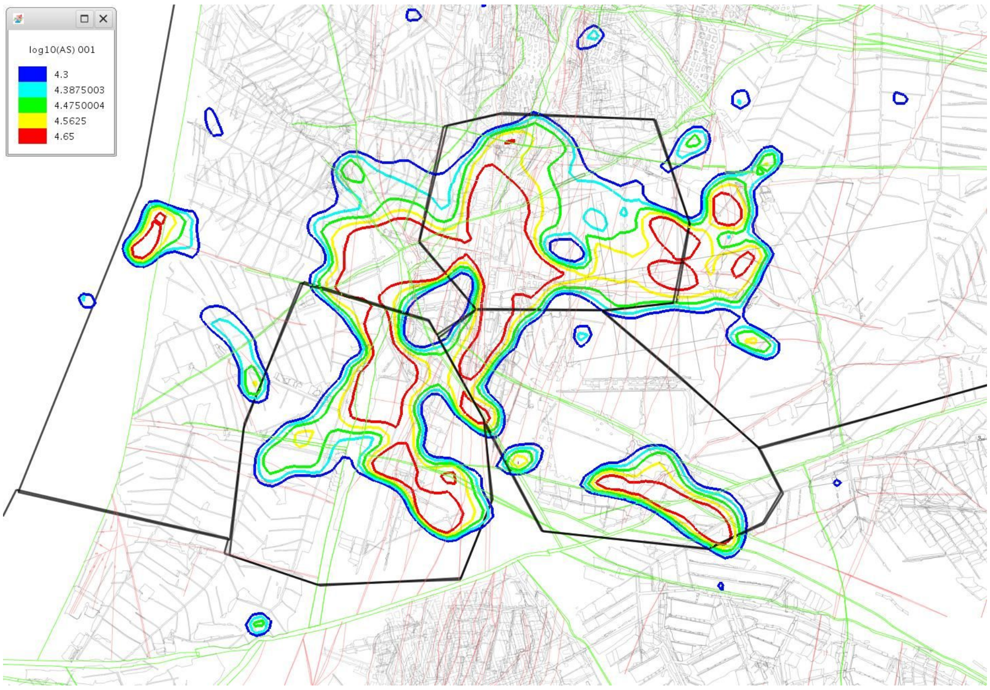

Figure 7: High apparent stress correlate with geological structures

1.7. Safety Statistics

Despite the adverse conditions that prevail on the mine, safety is a high priority. The last fatal accident occurred on 16 April 2004 and there has been a consistent decline of all accidents resulting in loss of man-hours since 2002 to date (Figure 8).

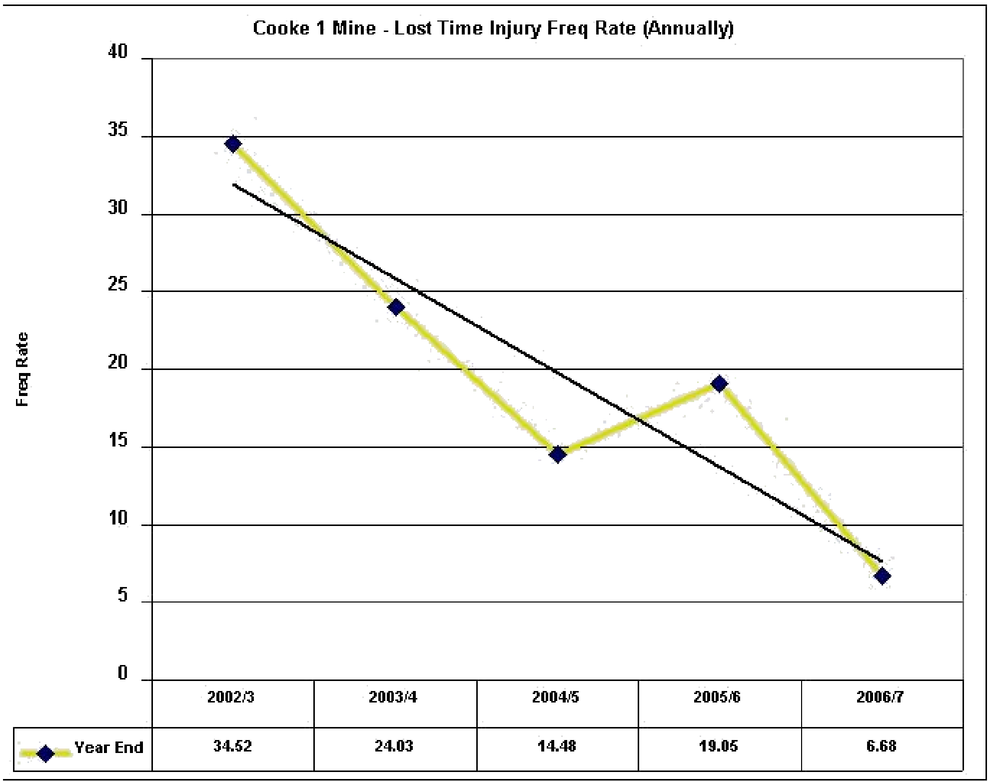

Figure 8: Injury frequency over time

Cooke 1 has consistently excelled in a safety competition organised by the Association of West Rand Mine Managers. In this competition the mine occupied second place last year and occupies first place in the year to date.

2. ORIGIN OF PILLARS

Pillars can be divided into two categories: those that were designed and those that were left unintentionally. Designed pillars include regional stability pillars, excavation protection pillars and stability pillars (clamping pillars) on structures. Unintentional pillars would have been left for one or more of a variety of reasons including grade considerations, fires, seismicity, deterioration or collapse of infrastructure or even because ground elsewhere would have been easier to mine.

A large proportion of the pillars currently extracted at Cooke 1 were original left as designed regional stability pillars. The original strategy was to provide regional stability by leaving, where possible, pillars against and on both sides of major, especially water bearing structures. Where it was felt that these pillars alone were inadequate, 20m by 60m pillars were to be left. These were spaced 140m apart on strike and 90m apart on dip. The functions of these pillars were firstly to support up to the black reef interface thus preventing water inflow and secondly to compartmentalize stoping areas to prevent large scale collapses.

3. OVERALL PILLAR RECLAMATION STRATEGY

3.1. Overview

All pillars that were both high grade and accessible would be mined. The function of the Rock Engineering staff and other services is to provide ways of mining it safely. In other words the question was not "Can we mine it?" but rather "How can we mine it?" This philosophy still holds.

3.2. Mining shaft pillar

Following a favorable grade assessment report prepared during 1982, the original shaft pillar was reduced. About 1999, extraction of the rest of the shaft pillar commenced.

3.3. Mining high grade pillars against structures and other remnants

During, the course of mining the shaft pillar, other ground became available through opening up operations and high grade remnants were targeted. Mining the stability pillars along structures began. Some regional stability pillars were also mined.

During, and especially towards the end of mining the shaft pillar, other ground became available through opening up operations and profitable remnants were targeted. In particular mining the stability pillars along structures began. Some regional stability pillars were also mined, usually (but not always) with consent of the rock engineering department after having negotiated some trade off. For example, payable but inaccessible pillars might have been sacrificed for lower grade but more accessible pillars in the same area. In some other cases, stability pillars were left in situ on the UE1A horizon, but were completely undermined on the E8 horizon. Such pillars are considered ineffective for regional stability.

3.4. Mining grid stability pillars from the periphery inwards

Following strat-planning stability pillars that were left on a regular grid were to be extracted in a sequence starting at the further reaches of the mine and working concentrically inwards. Following this approach the ever-deteriorating infrastructure would be left behind and the mine would be freed from cumbersome maintenance. Large areas where stability pillars had already been mined, or were never left indicated that the regular system of inter panel yield pillars probably provide adequate regional stability on their own.

It remained to be seen however whether such a project was viable due to the geographical spread of the pillars, accessibility, time and financial constraints.

4. ARRIVING AT THE DECISION

The decision to mine any particular pillar is taken by the mining manager and ore reserve manager considering the findings of an investigating team. This team typically comprised a senior production mine overseer, the rock engineer, a senior geologist, a senior environmental and hygiene officer and safety personnel.

5. ENSURING SAFE EXTRACTION

The strategies for mining safely is based upon 4 corner stones:

- Limit as far as possible the rock wall deterioration
- Reduce exposure of people to adverse conditions
- Promote awareness
- Monitor

5.1. Limit rock wall deterioration

5.1.1. Off reef mining

Usually the existing crosscuts and haulages are re-habilitated if required rather than re-development. If the existing excavations are damaged due to the stress regime associated with a pillar to be mined there is no reason to believe that a new excavation would not be subject to the same adverse effects.

Where new tunnels have to be developed, the least problems have been experienced where these have been located within the 45° to 60° “de-stressing” zone. On occasion it is necessary to develop the footwall tunnel partially to allow the development of a travelling way and ore-pass, then stope ahead and complete the footwall development in a follow behind fashion.

The positioning of service excavations such as ore passes and travelling ways remains one of the biggest challenges in pillar mining. The stress gradients between de-stressed and highly stressed areas are very steep. Siting the excavation/reef intersection presents a conundrum: Locating it in the old mined out area necessitates mining through the fractured footwall of that old area, and as will be seen later in one of the case studies, this is potentially extremely hazardous. On the other hand, siting the excavation/reef intersection in the solid pillar necessitates mining through the steep stress gradient associated with the abutment.

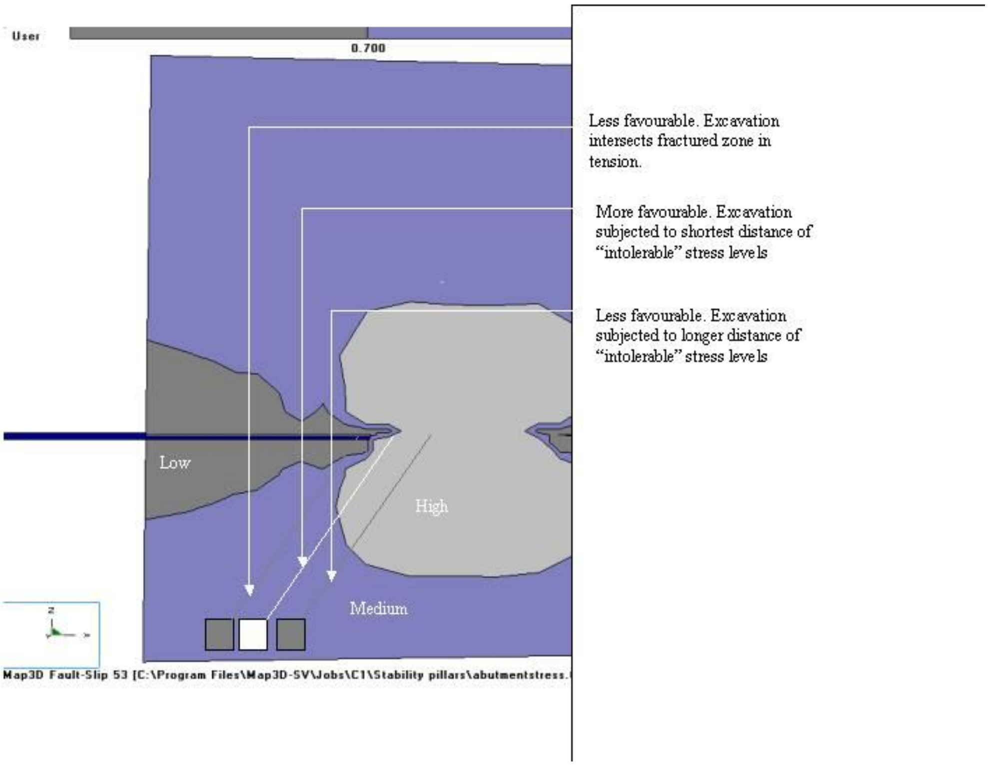

Figure 9: The most favourable position for access excavations - given the choice!

It has been found through experience, by and large, that aiming for a position just inside the solid block is the best option.

5.1.2. On reef mining

Without exception, all on reef development take the form of wide ends. This comprises a gully with shoulders on either side wide enough for two lines of timber packs. Not only does this pre-caution deal adequately with problems associated with post raise ledging, but also reduces the probability of entrapment of people in the event of a fall of ground.

5.2. Reduce exposure of people to adverse conditions

5.2.1. Pre-conditioning

Since the introduction and implementation of pre-conditioning towards the middle of 2004, the number of face burst related incidents has reduced drastically. The method of pre-conditioning that is employed is generally known as face perpendicular pre-conditioning. Holes twice the length of the normal shot holes are positioned strategically and timed to go off before the pre-ceding face shot holes.

Figure 10 show the dramatic effect that pre-conditioning in conjunction with the strict supervision has had in the first trial stope. The author is of the opinion that the correct blasting procedures brought about by the close supervision contributed significantly to the improvement of conditions in this case.

Before pre-conditioning	About 3 blasts after commencement of pre-conditioning	About 6 blasts after commencement of pre-conditioning

Figure 10: Illustrating the improvement in hangingwall conditions due to pre-conditioning and close supervision.

5.2.2. Safety Nets

It is compulsory in all pillars that safety nets be installed between workers and the rock face where workers are exposed to the rock wall for extended periods of time, e.g. the face, the tight end and the gully siding.

5.2.3. Increased support density

Timber packs are used exclusively as primary support with mechanical jacks as temporary support on the face. The standard calls for packs to be 1,8m apart, however usually they are installed even closer together. The last line of permanent support is not allowed to be more than 3,5 m from the advancing face before the blast.

All panels in Harmony, regardless of whether in pillars or not, must have additional hanging wall support in the form of tendons installed into the hanging wall. On Randfontein this support comprises full column grouted re-bar.

5.2.4. Mining direction

In most cases the pillars are extracted along the long axis. Although this frustratingly leads to less face length and slower production rates, the simultaneous exposure of people to face parallel fractures over a longer panel is less desirable. Mining this way has also almost completely eradicated the cutting of in stope yield pillars. It is difficult to justify two 3,0 m wide crush pillars on a panel of 8,0m total length!

It is believed that the higher support density justifies the omission of crush pillars.

5.3. Promote awareness

Many procedures are in place to make workers continuously aware of the hazardous conditions underground and in an attempt to combat complacency and promote alertness. These include:

- Numerous safety campaigns on a group and mine basis.
- Miners are expected to conduct safety meetings with their gangs on a daily basis.
- Coaches are expected to identify potential hazards on which to base weekly and monthly safety topics.
- The mine provides continuous formal skills training and evaluations.
- Informal on the job training by rock engineering and safety personnel is provided on a continuous basis.

- Inter-shaft and intra shaft safety audits are conducted on a regular basis and the results are conveyed to and followed up by senior management.
- Planned task observations have been integrated into the planning and control functions of management, as have risk assessments according to the Harmony Risk Management System.
- Monthly panel hazard ratings are conducted by the rock engineering department and results reported back to production personnel.
- Miners are obliged to declare their work places safe before any person may enter. On Cooke 1 the miner must be able to produce such declaration on demand to any person.
- Random one-on-one interviews are conducted with workers in an attempt to convey important safety issues, test the awareness and knowledge of workers and survey the effectiveness of information dissemination.

5.4. Monitoring

A seismic monitoring system is operative on the shaft and a contracted seismologist generates daily and monthly reports. Meetings take place with the Seismological consultants on a continuous basis and periodic formal meetings are held to discuss the seismic hazard of the mine.
Mining scenarios are back-analysed from time to time through numerical modelling and compared with actual rock mass behaviour in an attempt to better understand the rock mass response to mining and to calibrate modelling parameters.

Where modelling has been undertaken prior to mining, the predictions are checked against actual response and deviances and discrepancies are investigated.

Compliance to support standards is monitored formally by surveyors and their findings are reported on the survey layouts. These layouts are scrutinised and signed off by all the role players directly concerned with the management and control of every work place.

Safety statistics are scrutinised by the safety department on a daily basis. In this way trends are normally identified early and rectifying measures can be taken.

Apart from daily communication with production personnel, the rock-engineering department also uses the monthly planning meetings as a forum for following up on recommendations made during the month.

6. CASE STUDIES

6.1. Window bowl

The window bowl area has a long history of mining. It started out as a trackless section with, 8,0m x80m bords and pillars. Because of the high grade in the area, the pillars have been reduced several times. Pllar reclamation is taking place during 2007.

The window bowl is the bottom of the bowl described in section 1.2 of this report. The hanging wall is very competent and stable with local instabilities coinciding with geological structures. Despite the de-stressing effect of the extensive undermining on the E8 reef horizon about 30m below, some pillars have scaled to about the size of packs!(See Figure 11)

Figure 11 : Scaled pillars in the window-bowl

The present pillar reclamation operation is viewed as the last opportunity to reclaim pillars from this area. Mine-able pillars have been identified on the basis of grade, accessibility and impact on stability.

The main risk factors from a Rock Engineering point of view are:

- Local falls of ground due to instability caused by the combination of excessive spans and geological discontinuities,
- Pillar bursts
- Catastrophical regional collapse due to a pillar run.

The above factors having been taken into account, a program of mining was drawn up in which reclamation of pillars would take place on a retreat basis.

The main access way was supported with timber packs and the identified pillars were mined using conventional scraper mining, using timber packs for support. The broken ore would be scraped into the adjacent roadway from where it would be removed by front end loaders and dump trucks. This is locally known as semi-trackless mining.

A number of the identified pillars have been mined in the recommended sequence, without serious incidents. No strain bursting has been reported and the hangingwall did not deteriorate substantially. However, in the one instance when a pillar was mined parallel to and towards the roadway some 20 m above, a seismic event of 0.9 caused damage to that roadway and the diesel storage bay.

Subsequent pillars were mined parallel to the roadway and in the direction of the longest axis of the pillar.

6.2. Mining Sequence for 101 E 3

The area concerned is a relatively narrow completely isolated block of ground as presented in Figure 12.

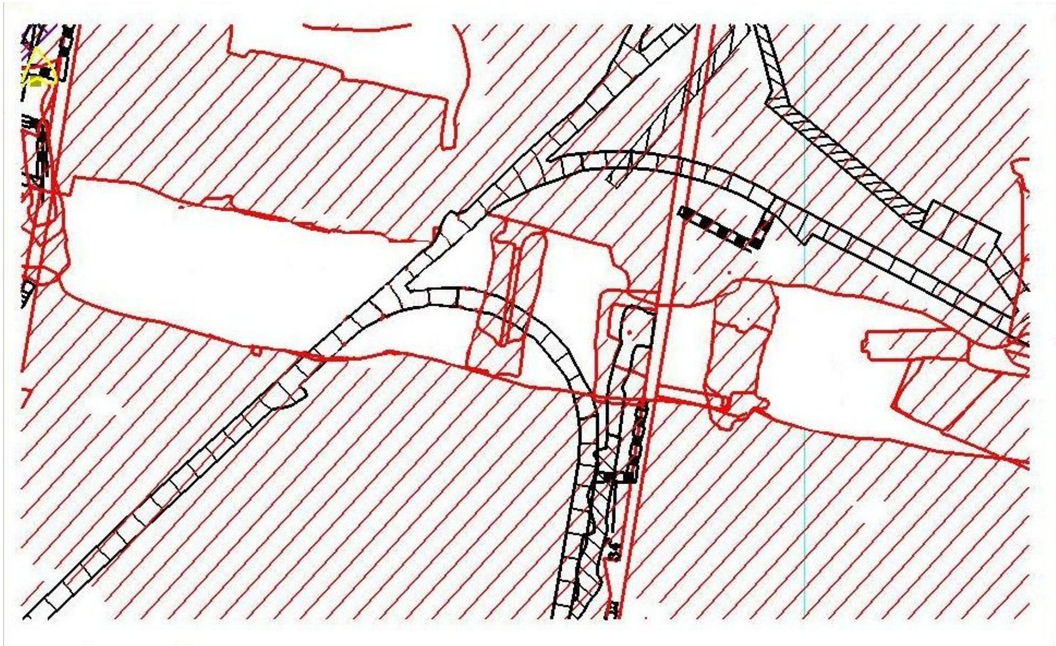

Figure 12: The original configuration of 101 E 3 before the gully collapsed.

It was planned to access the pillar by establishing gullies in the back area through footwall lifting and then to develop two wide raises, one for the western portion of the pillar and the other for the substantially smaller eastern portion of the pillar. The eastern portion would have been mined out to the limit before the western portion could be advanced. However, due to lack of hanging wall support the gully of the eastern portion collapsed. In order not to lose production, consideration was given to mining the western portion while rehabilitating the eastern portion. The western portion was modelled as mined to a position such that the area mined would be about as big as the eastern portion.

6.2.1. Mining both portions at the same time

In this scenario, about twenty meters of the western portion was modelled in the first stage, after which both portions were modelled as mined. The modelled mining steps are presented in Figure 13.

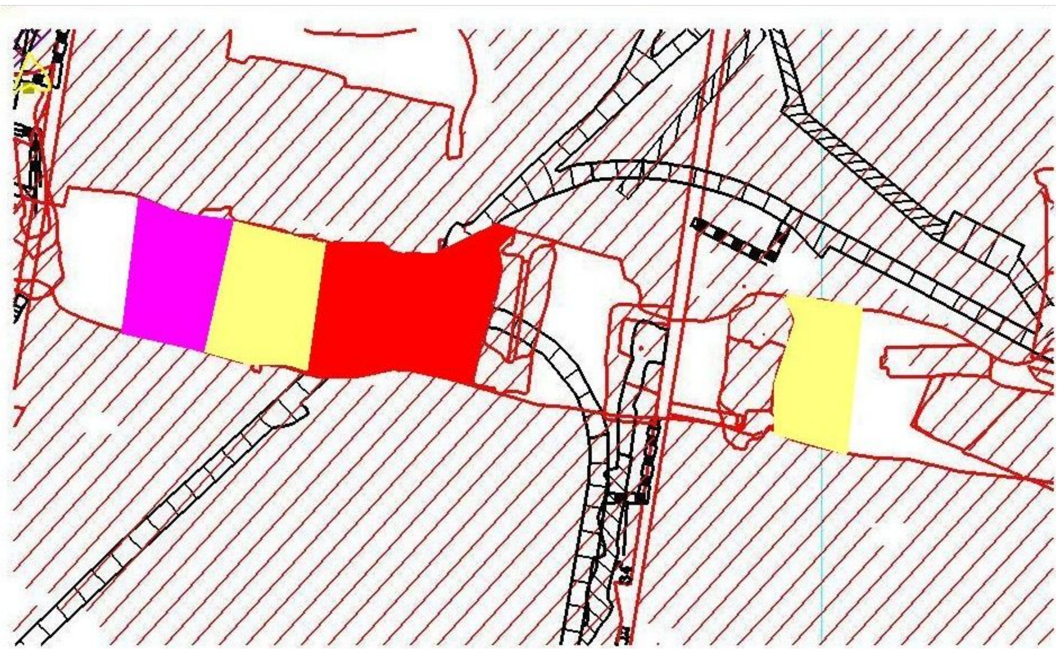

Figure 13: The western portion is mined initially. The remaining stages are mined simultaneously.

6.2.2. Conclusions derived from modelling

Figure 14 depicts graphs of the average stresses for each mining scenario. Based on the assumption that conditions will be worst if stresses are highest, the following conclusions were drawn:

- The western portion was virtually unaffected by mining the eastern portion if the latter were to be mined first.
- Stresses in the eastern portion, in general would have been higher than in the western portion if the latter were to be mined first.
- If both portions were to be mined simultaneously, very high stresses would have developed in the eastern portion
- If the western portion were to advance more than about 20m, it would have become extremely difficult to mine the eastern portion

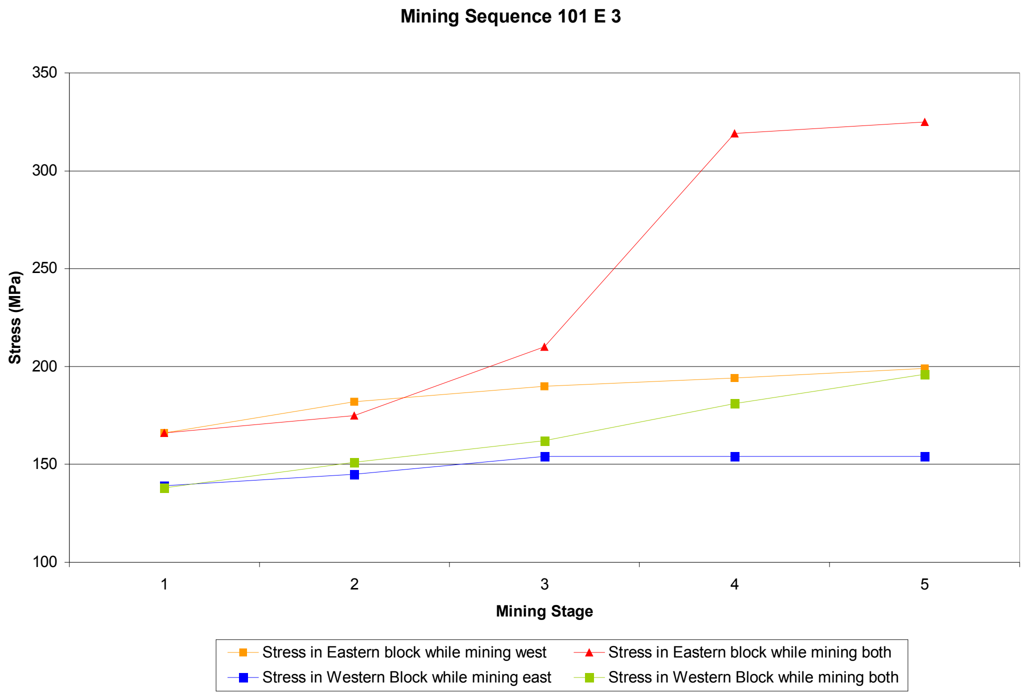

Figure 14: Summary of results

6.2.3. Final result

- Mining of the western portion commenced while access to the eastern portion was re-established, and then the pillar was mined by advancing in both directions at the same time.
- The eastern portion was extracted to the limit before the western portion advanced more than 20m.

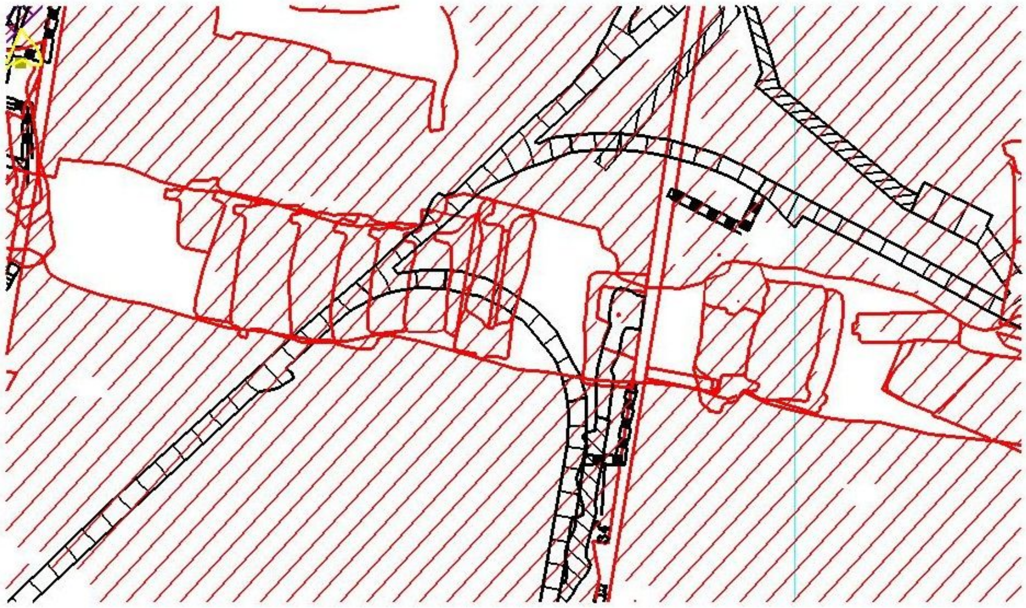

Figure 15: 101 E3 final configuration.

6.3. 95 W 2

A narrow strip of reef was left in –situ against an east-west orientated dyke to act as a stability pillar as presented in Figure 16. The dyke in question intersects another north-south dyke, which is known to be seismically active. There was concern that mining the pillar according to the original plan would result in increased seismic activity associated with both dykes.

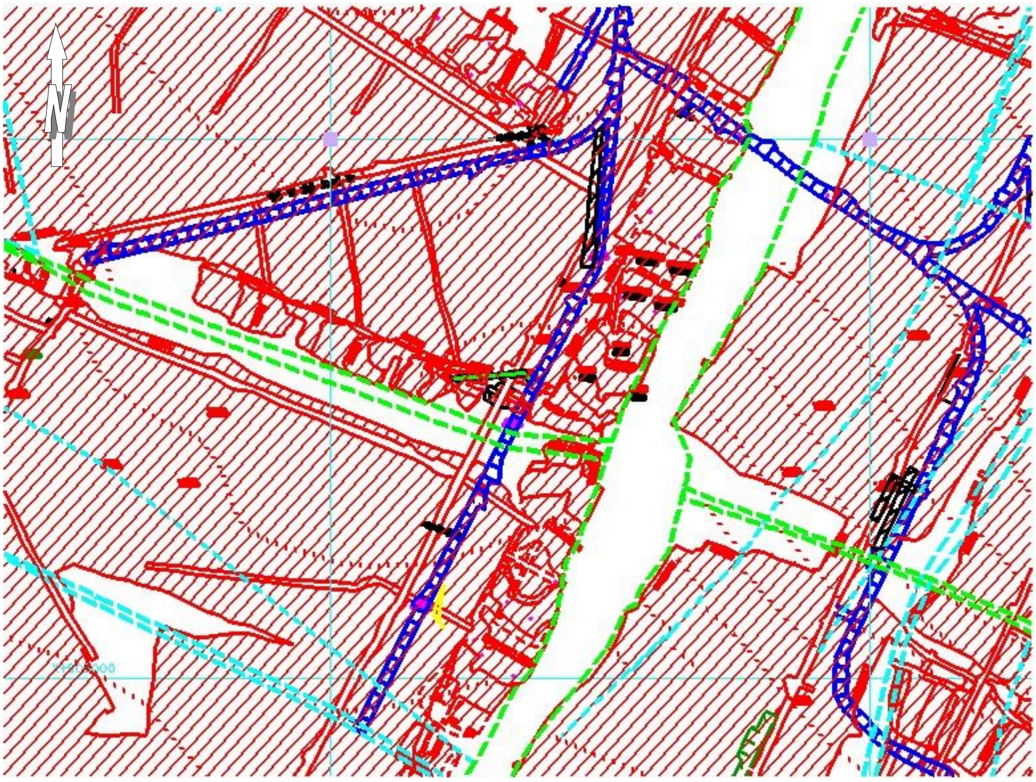

Figure 16:The 95 W 2 pillar, showing the two dykes of concern

A numerical model was built to qualitatively assess the potential for seismicity by analysing excess shear stress. For the purpose of this analysis it was assumed that slip is likely to take place when the magnitude of excess shear stress is 10 MPa or more. It was further assumed that

larger areas subjected to excess shear stress of such magnitudes might give rise to larger magnitudes seismic events.
The modelling revealed that mining along the north-south dyke would not significantly affect the east-west dyke provided a large pillar was left in situ.

Additional scenarios were modelled and it was determined that mining both sides of the dyke in any direction could result in consistent seismic activity at the stope face, and might threaten the stope infrastructure. On the other hand, mining either the south or the north side of the dyke would result in less seismicity

It was decided to mine the North side because of practical mining considerations. The face had to be re-established on two occasions after moderate damage occurred due to falls of ground associated with small magnitude events but the pillar was successfully extracted.

6.4. The Three Sisters and the Poodle

The "three sisters" refer to three extremely isolated and high grade pillars previously reserved as regional stability pillars, however upon inspection it was decided that these pillars were redundant as such, hence they were the first regional stability pillars to be mined that were not against geological structures.

Continuous monitoring indicated no seismicity whatsoever. The pillars were not able to store energy and simply yielded with closure rates comparable to much deeper mines.
The Poodle (the origin of the name of which is obvious from Figure 17) was situated in the same block of ground and was mined after extraction of the three sisters.

A new ore pass had to be developed for the Poodle, and it was aimed to intersect the old stope because, so it was thought, this would be less hazardous as the ore pass would be completely de-stressed. Before the ore-pass intersected the old stope, about 600 tons of broken rock came down, fortunately during the off shift. Later investigations showed a crater in the stope below the reef at the top of the ore-pass with a radius of approximately 3 m and about 2 m deep. The entire footwall fracture zone had fallen down the ore pass. Subsequent to this incident, all travelling ways and ore passes were aimed to intersect the reef in solid as close as practicable to the edge of the pillar.

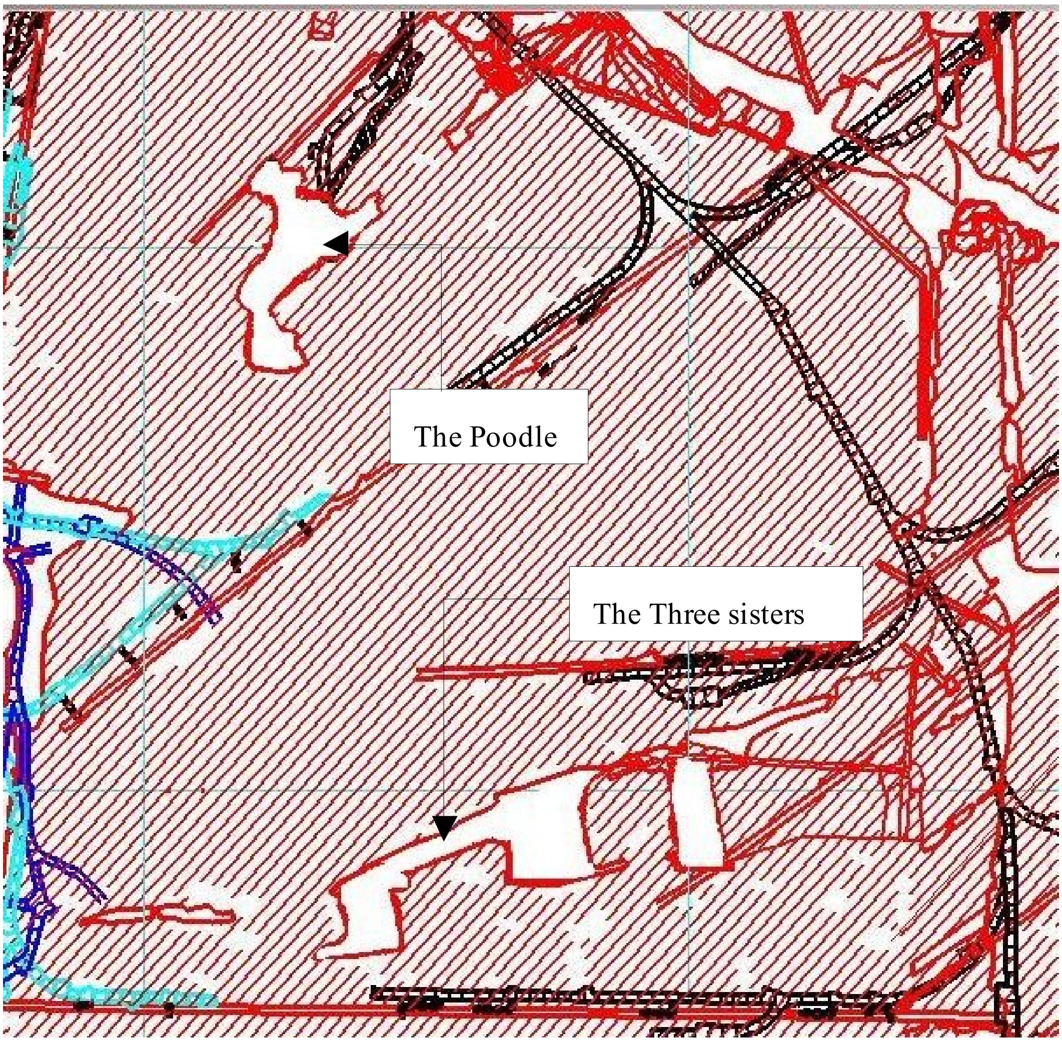

Figure 17: The Three sisters and the Poodle

Mining the Three Sisters and the Poodle showed that much larger areas could go without regional stability pillars than was catered for by the original design. In future, the hydraulic radius of this area might be considered as a criterion for mining stability pillars.

7. CONCLUSION

The above examples illustrate a few of many diverse challenges faced with when mining pillars. The successes achieved here and elsewhere show the way forward in tabular mining in the future.

8. ACKNOWLEDGEMENTS

Harmony Gold Mining Company Ltd.
Brently, Lucas and associates.
The exceptional team at Cooke 1 shaft.

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