PRE – CONDITIONING
A TOOL TO COMBAT FACE BURSTS
AT MPONENG

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Mponeng is a seismically active deep level mine. As the mining depth increases, so do the stresses ahead of the mining faces. Consequently the probability of face bursting also increases. Due to the depth and the properties of the rockmass (hard, brittle hangingwall lava), the occurrence of face bursting is a problem. Seismicity accounts for some 50% of all mine fatalities on Mponeng. Over the past few years significant improvements have been made in reducing the rock related injury and seismic rates. This was achieved by changing the overall mining layout as well as the support strategy. Although the change in mining layout, from longwall to sequential grid mining, reduced the occurrence and size of the large events, face bursting remained a problem. Considering the seismic fatalities since 1997, 60% were as a result of events below magnitude 1.5 and 30% was attributed to face bursting. As pre-conditioning is currently the only tool available to combat face bursting it was introduced on Mponeng. Since the implementation of pre-conditioning the occurrence of on-shift face bursting have reduced, significantly reducing the associated injury rates.

INTRODUCTION TO MPONENG

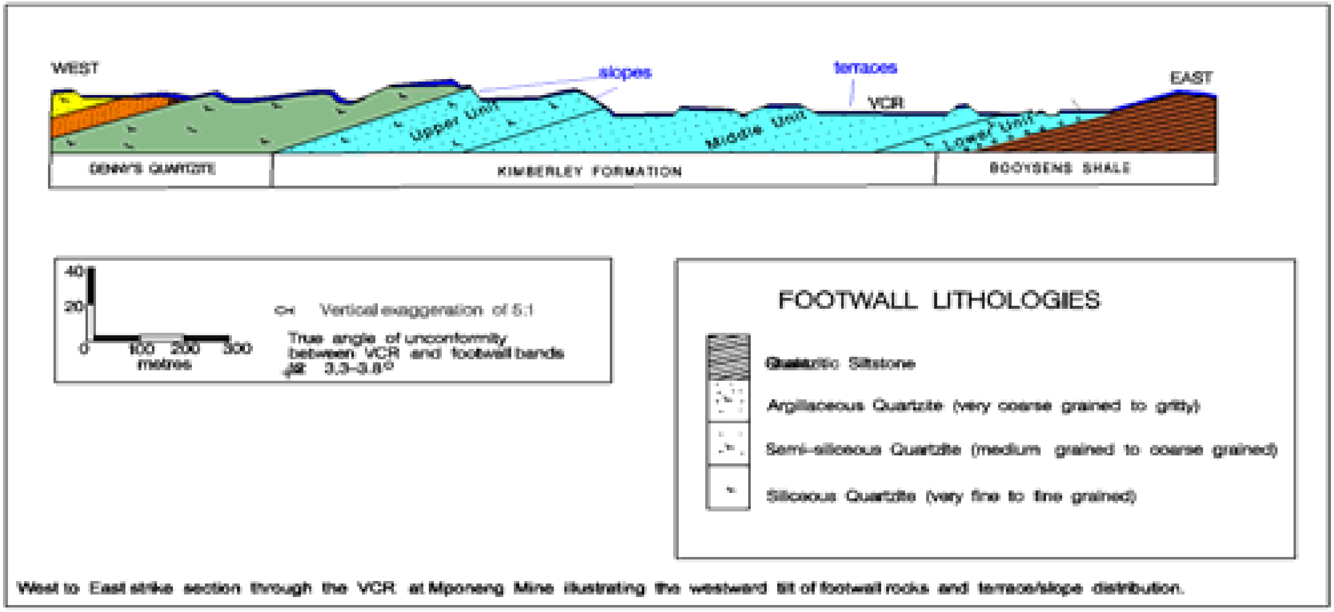
Mponeng, previously known as Western Deep Levels South or No. 1 Shaft, means "Look at me".
Mponeng is situated on the West Wits line of the Witswatersrand basin. Mponeng lies on the Gauteng/North West province boundary, some 70km South West of Johannesburg, midway between the towns of Carletonville and Fochville. Mponeng produces gold exclusively from the Ventersdorp Contact Reef (VCR) a quartz pebble conglomerate.
Mponeng Mine has a twin shaft system. The main shaft was commissioned in 1986 and the sub shaft in 1993. The mine is also known for the unique application of ice for the refrigeration of the underground workings. The mine employs 5600 people of which 3500 is on direct production. Mponeng mines some 28 000m^2/month at an average dept of 3 200 metres below surface at an average stoping width of 1,4 metres. Mponeng mines this volume by means of the sequential grid mining method. This method makes use of dip pillars and reduced mining spans with pre-developed tunnels.

THE VENTERSDORP CONTACT REEF AT MPONENG

The Ventersdorp Contact Reef (VCR) rests on the top of the 11,000 metre-thick sedimentary package of the Witwatersrand Basin. This makes the reef unique in that its immediate hangingwall is, unlike other reefs, not a quartzite but Ventersdorp Lava.

At Mponeng Mine, the VCR comprises of a highly variable, quartz-pebble conglomerate that ranges from a single pebble layer to a maximum of 3 metres in thickness, with an average thickness of around 85 centimetres. The VCR also commonly contains internal quartzite bands.

The footwall on which the VCR rests was tilted westwards prior to the reef being laid down. As a result, different footwall rocks are exposed beneath the VCR across the mine. These vary from a shale (the Booysens Shale) in the east, to a tough, competent quartzite (the Denny's Quartzite) in the west. The centre of uplift that caused the tilting was the Bank Anticline, located on the neighbouring Driefontein Mine. The associated uplift caused pebbles and sand from the footwall bands to be eroded by rivers and deposited further downstream, in the vicinity of Mponeng, as the VCR



West to East strike section through the VCR at Mponeng Mine illustrating the westward tilt of footwall rocks and terrace/slope distribution.

Figure 1 schematic section through the VCR showing the nature of the reef on its footwall.

As the rivers flowed over the different footwall rocks, the type of conglomerate that was deposited also varied. Thick reef was deposited on the softer bands which yielded more to the erosion of the rivers (especially the Booysens Shale and middle Kimberley quartzites), while thinner reef was deposited on the harder bands which were more resistant to erosion (upper Kimberleys, parts of the Denny's and Elsburg quartzites).

Numerous cycles of river erosion and conglomerate deposition occurred over a significant time span. As each cycle repeated, the river cut progressively deeper channels into the already consolidated sediments. This created abandoned terraces of sediment which contained material from previous depositional episodes.

Ultimately, several of these terraces were created that were perched at different levels above the river. Each terrace was separated from those around it by ‘slope’ reef, comprising a thin veneer of pebbles on a steeply dipping surface.

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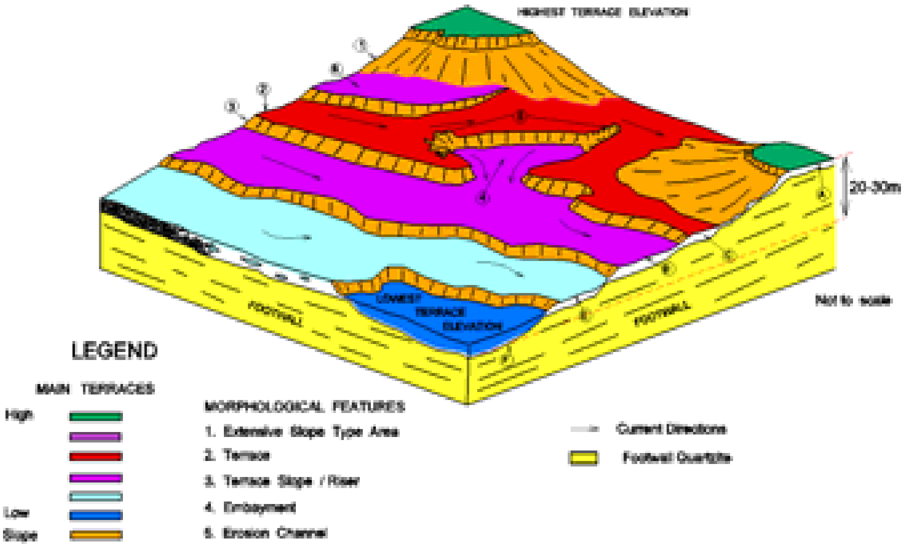


Figure 2: an isometric view illustrating the formation of the terraces and slopes at Mponeng.

The resulting VCR topography at the time of conglomerate deposition was highly complex, with numerous inter-fingering channels, terraces, and inconsistently developed slope reef separating each terrace.

The entire system was finally capped by massive outpourings of lava, which sealed and preserved the undulating VCR topography. The overall maximum elevation difference between the lowest and highest terraces on Mponeng is in the order of 30 metres. These elevation differences between terraces must be negotiated during mining operations.

Although Mponeng’s structure in terms of faults and dykes is relatively straightforward compared with other West Wits mines, the unpredictable nature of terrace/slope boundaries poses very special challenges.

Whereas the trends of faults and dykes tend to be predictable between adjacent raise lines, the orientation of terrace/slope edges is never linear. The intersection of an unforeseen down-slope in a stope face could lead to premature face abandonment. Detailed geological facies mapping and the use of predictive tools such as borehole radar surveying are therefore of great importance in optimising orebody extraction.

The lava that overlies the VCR is tough, very fine grained basalt with distinct flow banding. Bedding parallel jointing is a common feature of the lava. The joints are often filled with a veneer of calcite or clay minerals. The lower contact with the VCR can be "frozen", or represented by a contact-parallel fault zone filled with fault gouge material. Hangingwall parting along this contact zone occurs frequently during mining, resulting in a smooth roof profile. Frozen contacts appear to be more common on the Eastern side of the mine, whilst faulted contacts are often associated with the Denny's footwall zone on the Western side.

HISTORY OF PRE-CONDITIONING

Pre-conditioning or de-stress blasting started at ERPM in the early 1950's. Incidence of rockburst per area mined were reportedly reduced by 36%, severe rockburst events by 73% and on-shift events dropped to almost zero during the testing period. This was however not accepted by the mines as a viable and safe mining method and subsequently stopped (Roux. Et al 1957).

SIMRAC re-investigated pre-conditioning in the late 80's. Long hole, face parallel pre-conditioning tests started at West Driefontein and Blyvooruitzicht GM in 1990. This was not successful from a production view point as it caused production delays.

Tests on face perpendicular pre-con in a Long wall started at Mponeng (then Western Deep Levels South) in 1994. Although successful it wasn't pursued after the testing was completed. Various attempts were made to do pre-conditioning mine-wide, but it was only in the beginning of the 2000's that it was rolled out and enforced mine-wide (GAP 336).

MINING INDUCED SEISMICITY

A seismic event is defined as "a sudden inelastic deformation within a given volume of rock." (A Handbook on Rock Engineering Practice for Tabular Hard Rock Mines – Jager, A.J and Ryder, J.A. - SIMRAC 1999). These inelastic deformations are caused by the sudden release of elastic strain energy stored in the rock mass surrounding excavations. This strain energy arises from the elastic deformation within the surrounding rock mass due to mining, or more simply, stope closure. Several seismic event mechanisms are postulated, the most common being slip on a major or minor discontinuity in the rock mass.

These discontinuities can be geological such as faults, dykes and joints, or mining induced shear fractures along abutments. Strain bursting is another common mechanism experienced on Mponeng whereby a small volume of rock at a stope face fails violently resulting in face ejection.

The Mponeng seismic network records some 1000 events daily ranging from magnitudes of –0,3 upwards. Only a small subset of these events, referred to as rockbursts, cause damage to workings and injuries to people. Of the events recorded, less than 1% are potentially damaging (200 events/month) and of these some 60-70% occur off-shift with the blast and hence may damage workings but do not cause injury. The damage/injury potential of an event depends on its size (e.g. magnitude), proximity to current working places, ground conditions in working places and the local support installed. Management of seismicity involves reducing the number of damaging events in current workings. This can be done by firstly reducing the overall level of seismicity in their vicinity as well as improving ground conditions and the quality of support systems to lessen the effects of seismic events

Any management of seismicity strategy must consist of two main thrusts: the macro strategy (mine design) addressing mining layout, regional support and extraction sequence; and the micro strategy addressing local support, preconditioning and strata control.

PRE-CONDITIONING MECHANISM (FACE PERPENDICULAR PRE-CONDITIONING)

Pre-conditioning is aimed at transferring the stresses away from the stope face through remobilising the existing fractures in the rockmass and to prevent the accumulation of strain energy ahead of the working face and therefore reducing the potential for face burst damage.

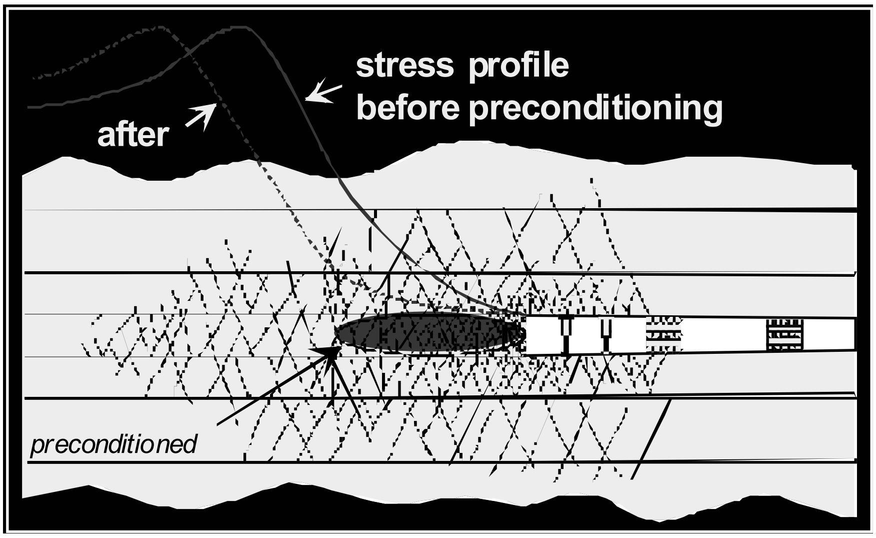


Figure 3 Idealised stress profile ahead of a stope and intended stress transfer by pre-conditioning.

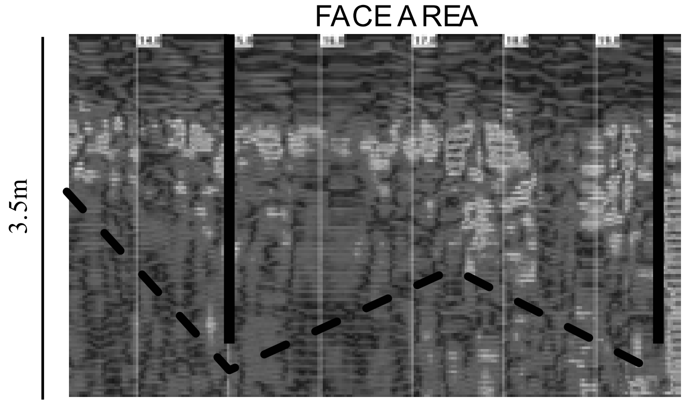
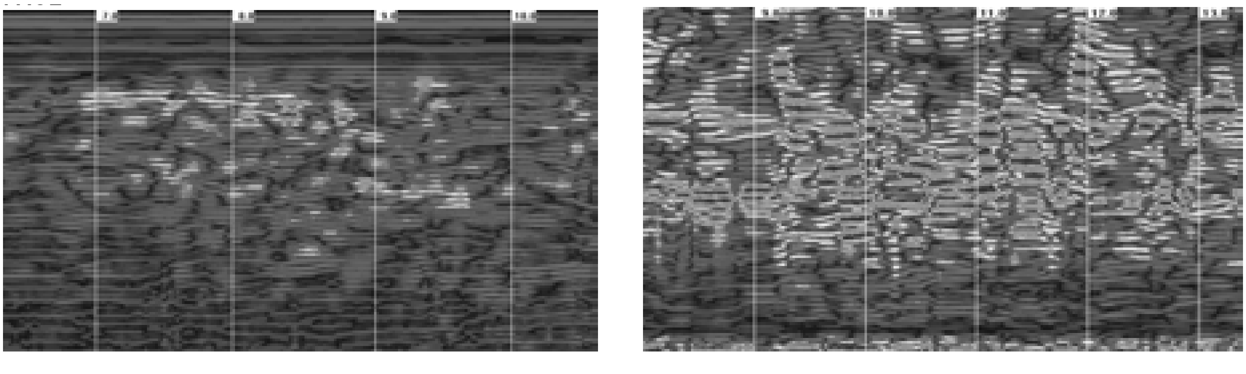


Plate 1: Ground Penetrating Radar (GPR) scan of the fracture zone ahead of a pre-conditioned mining face.

The stress redistribution provides a low-stress cushion ahead of the stope face that is able to absorb energy from distant events.

Plate 2: GPR scan of the fracture zone of a pre-conditioned and non pre-conditioned face.



Non Pre-conditioned face

Pre-conditioned face

Pre-conditioning involves the setting off of a designed blast ahead of the stope face. This is achieved by drilling holes into the face, at a certain burden, that are longer than the normal production holes. These holes are charged up and blasted with the production rounds. It is essential that the pre-conditioning holes are timed to go off prior to the production holes.

Implementation of Pre-conditioning on Mponeng : Layout

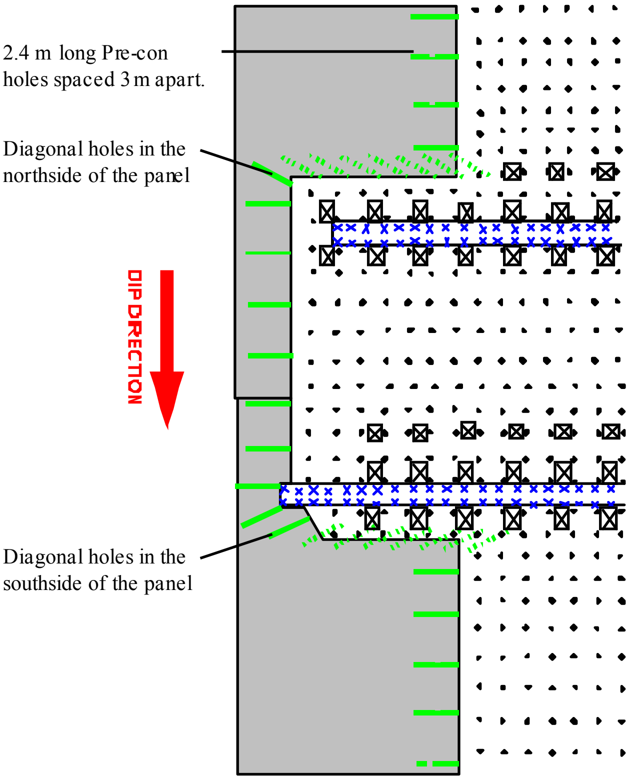


Figure 4: Pre-conditioning layout.

Face perpendicular pre-conditioning involves the drilling and blasting of 2.4 m (minimum) long face perpendicular holes, 3 m apart with every production round. The row of pre-conditioning holes is drilled in the centre of the face between the hangingwall and footwall of the stope.

Charging up

Approximately 2/3 (1.4 m) of the drilled hole must be charged with explosives. The detonation of the hole should be by top-priming the explosive charge, to facilitate removal of primers from misfired holes. Stemming of the holes is very important as an effective stemming will maximise the stemming retention time, which will contain the explosive energy in the hole for as long as possible. Poor or no stemming can result in misfires of the production holes. The remaining 1/3 of the hole must be tamped with competent stemming material.

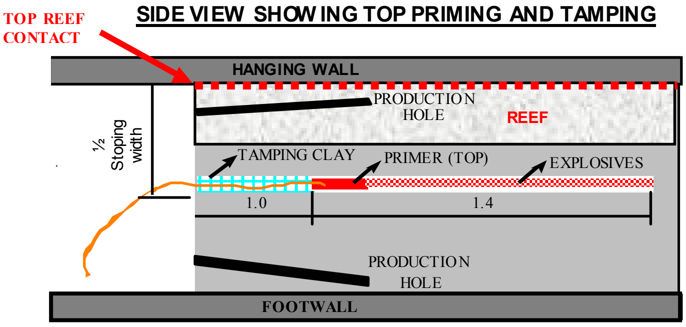


Figure 5: Charging up of the pre-conditioning hole.

Detonation sequence

The timing of the pre-conditioning hole relative to the production holes is very important. Poor timing may lead to ineffective pre-conditioning and / or misfires. The pre-conditioning hole should be timed so that detonation of the hole will take place approximately 1.0 m ahead of the production holes.

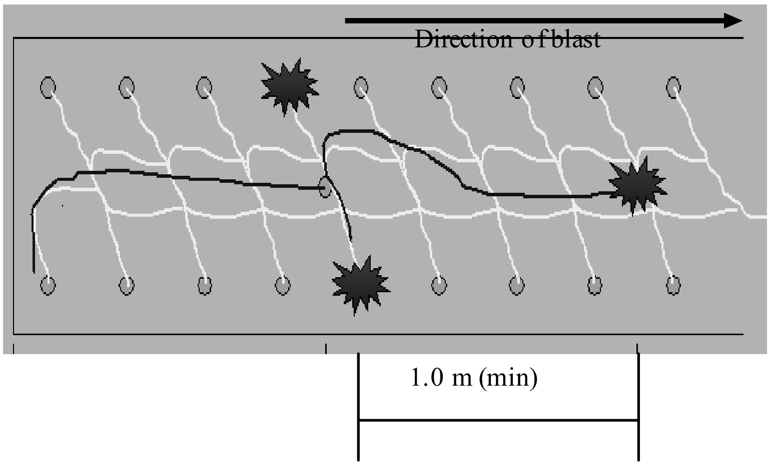


Figure 6: Detonation sequence of the pre-conditioning blast.

PROBLEMS AND ACTIONS

Charging up of the pre-conditioning hole

The initial recommendation was to charge up the first metre of the hole (± 5 cartridges AEL 200 mm Powergel). The primer is then placed behind the explosives, which in theory would give you a 1.2 m charged hole. However with the forcing of the explosives into the holes, this effective charged portion of the hole is much less than is called for. This resulted in creating a poorly developed fracture zone in the immediate face area. After initial investigations into the application of the pre-conditioning, it appeared to be sub-standard. Only after dressing the face and removing the initial face slabs could the proper fragmented zone around the pre-conditioning sockets be observed.

A subsequent change in the standard was made. The standard specifies that the first 1.4 m of the hole must be charged up, including the primer. After the charging up of the hole is done, the person in charge must ensure that only 1.0 m of the hole remains that needs to be tamped.

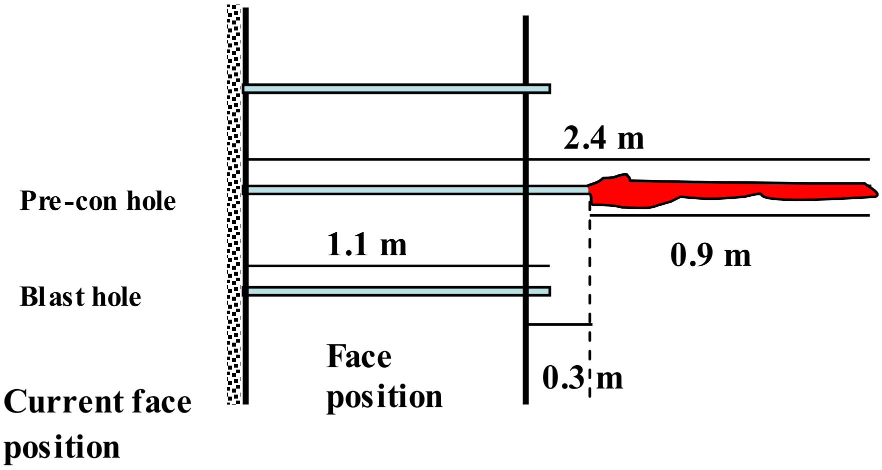


Figure 7 indicates the problem encountered with the pre-conditioning hole detonating in front of the blasted face.

Position of the pre-conditioning hole (high stoping width > 1.8 m)

During 2000, the effectiveness and application of pre-conditioning blasts at high stoping widths was questioned, which resulted in a SIMRAC project (GAP 811). The final report recommended that the pre-conditioning holes be drilled a maximum distance of 0.6 m from the hangingwall to eliminate the occurrence of overhanging faces.

Plate 3: Overhanging face.

The dangers associated with overhanging faces are recognised and the creation thereof may not be allowed. There is however a practical implication of drilling a pre-conditioning hole 0.6 m from and parallel to the hangingwall.

Drilling the hole at an angle of more than 14° to the hangingwall will result in the hole being drilled into the hangingwall resulting in hangingwall damage. Due to the length of the stoping airleg, drilling a 2.4 m long hole parallel to the hangingwall can only be achieved by commencing the drilling from the top of broken rock in the panel. This is not possible if the panel has been cleaned.

Another issue was the variable stoping width in a panel, which can range from < 1.0 m to > 2.0 m within a panel. At a low stoping width, a row of pre-conditioning holes is drilled in the middle between the hangingwall and footwall. Having two different pre-conditioning standards within a working panel can cause confusion. A decision was made to drill the line of pre-conditioning holes in the middle between the hangingwall and footwall to eliminate the problems mentioned above and to produce only one pre-conditioning standard.

Pre-conditioning itself is not the root cause of overhanging face. Overhanging faces is also the result of poor blasting practices and therefore it will be addressed as it occurs and removed during the entry examination and before drilling of the production round commences.

Negotiating rolls in the reef

Erratic and severe dip and strike rolls are encountered when mining the VCR reef at Mponeng. When mining breast the position of the majority of the dip rolls only become known when they are exposed. Therefore no precaution can be taken beforehand. The production crew normally only knows of its existence once it is too late. The exposure of rolls or the mining in rolls is often associated with an increase in seismicity as the drilling and blasting takes place inside the hard, brittle Ventersdorp hangingwall lavas. The occurrence of face bursting increases as the lavas are exposed (Figure 8).

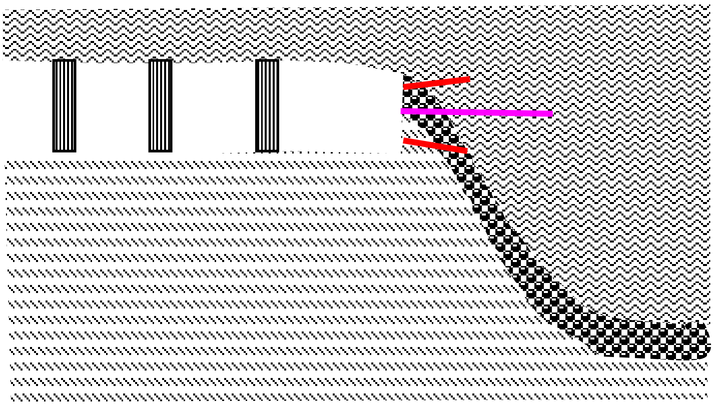


Figure 8 : Drilling into the lava hangingwall with the production as well as the pre-conditioning hole.

Poor hangingwall conditions are encountered with the exposure of rolls, due to blasting damage caused by the drilling and blasting of the production hole into the hangingwall (Figure 8B and C).

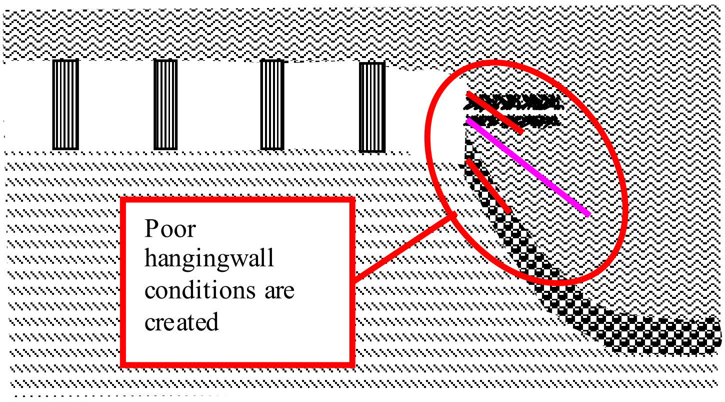


Figure 8B: Continuous drilling into the hangingwall lavas while negotiating the roll creates poor hangingwall conditions.

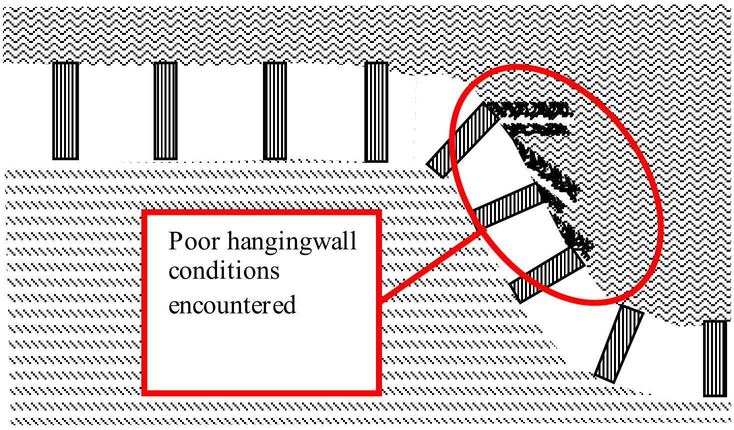


Figure 8C: Poor hangingwall conditions are encountered in the roll.

Additional damage caused by pre-conditioning is questionable. Analysis done by SIMRAC (GAP 030) on the forming of fractures indicates that no new groups of fractures are formed in the hanging wall with the introduction of pre-conditioning. There was a relative change in the abundance of the existing fracture groups. There is an increase of approximately 25% in steep dipping fractures, whilst shallow dipping fractures showed a decrease of 61%. Fractures of intermediate dip showed very little change in abundance between the pre-conditioned and non pre-conditioned areas.

Exposing the lava hanging wall leads to an increase in the occurrence of face bursting. As stated previously, pre-conditioning is the only tool that reduces the occurrence of and the damage associated with face bursting. The support system has to deal with the deterioration of the hanging wall. More stringent support and the use of headboards will provide an increase in area coverage and support resistance. In some areas pinning of the hanging wall is done.

Locating the Pre-conditioning sockets after the blast

All sockets need to be examined for misfires after the blasting of a production round. It is even more important that the pre-conditioning holes are examined as they are charged up ahead of the blasted face position. Due to the “freezing” of the broken rock inside the sockets (if pre-conditioning done correctly) identifying and locating of the sockets does become a problem (Plate 4).

Location of the pre-conditioning sockets is essential for auditing, to ensure a true reflection of the compliance of pre-conditioning. In order to alleviate this problem, paint-lines 3 m apart, perpendicular to face are drawn against the hanging wall. These lines are extended with every blast and are an indication of the location in which the pre-conditioning holes would be found. This was a practical solution to reduce the time that was spent to look for the holes.

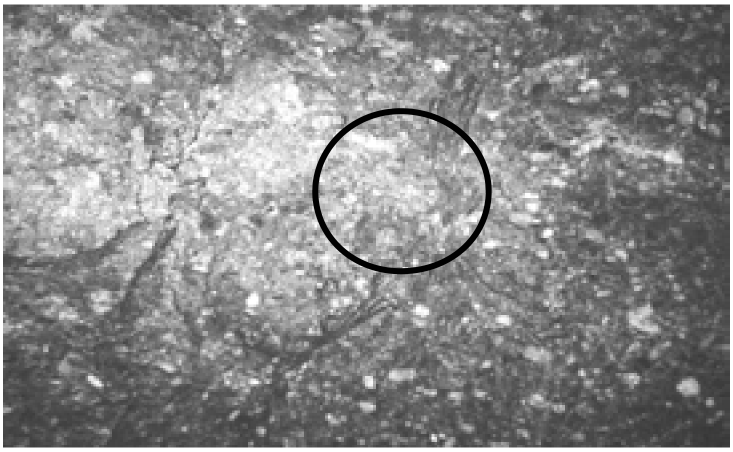


Plate 4: Pre-conditioning socket after the blast.

Quantifying the effectiveness of Pre-conditioning

New concepts and additional work bring about resistance to change. It is essential that the production crew experience the advantages of pre-conditioning. Once that is achieved they will ensure that it is done to standard.

Although implementing pre-conditioning started in the beginning of the 2000's, it was only in the first quarter of 2003 that a major effort was put into the application of proper pre-conditioning and the re-training of the personnel. It was also in this time that the stope audit system was implemented.
Some of the published additional advantages due to pre-conditioning are improved hanging wall conditions, better stoping width control, improved face conditions, increased face advance per blast, increased drilling rate, reduced fragment size of blasted reef and increased worker morale.

Seismicity and Seismic damage analysis

As seismicity is production driven, the number of seismic events are normalised against the production.
A seismic rate is given as the events per 1000 m^2 mined.

Previously published papers indicated the reduction in seismicity since changing from longwall to sequential grid mining. There is however a slight increase in the seismic rate during the past two years, since 2003. This is mainly due to the cutting of some pillars in the lower levels (Figure 9).

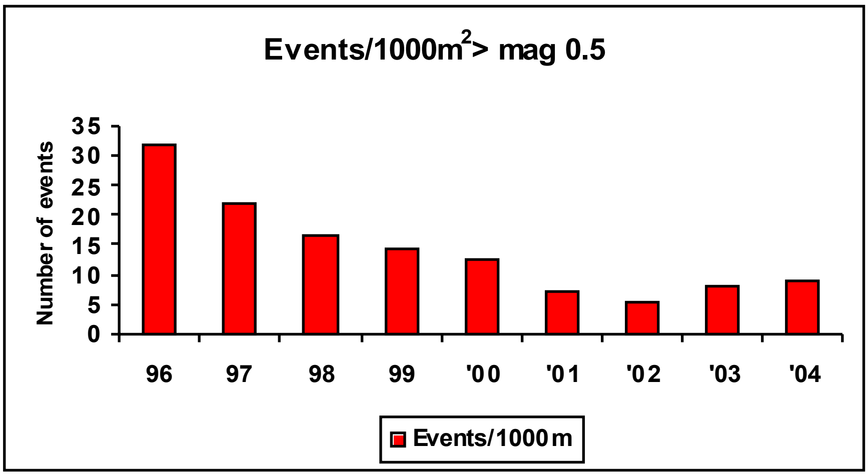


Figure 9: Events per 1000 m^2 mined.

Of the total number of events that occur on Mponeng, and average of 14% is above magnitude 0 and 2% above magnitude 1. Approximately 70 to 100 damaging events (M>1) occur on Mponeng during a month.

Analysis of the damaging events since January 2004 indicates that 34% of the damage is attributed to face ejection (Figure 10). The remaining 66% was either falls of ground or dynamic closure with no associated face bursting. As this database does not extend further back, these values are compared to the rock related fatalities between 1999 and 2001. As indicated in Figure 10A, 71% of the rock related fatalities were caused by face bursting.

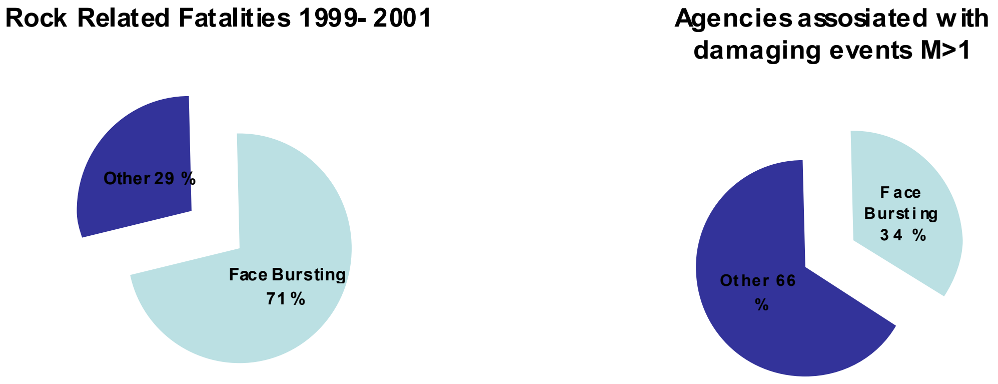


Figure 10 (A) indicates the % of fatalities attributed to face bursting during 1999-2001. (B) Indicates the current % of face bursting.

Evaluating the current damage caused by seismic events (M>1), a total of 574 seismic damage and Fall of Ground Management (FOGM) reports (since January 2004) were analysed. A total of 55% of the cases recorded no damage, 30% only minor falls of ground (< 5m) and 15% damage greater than 5 m (Figure 11).

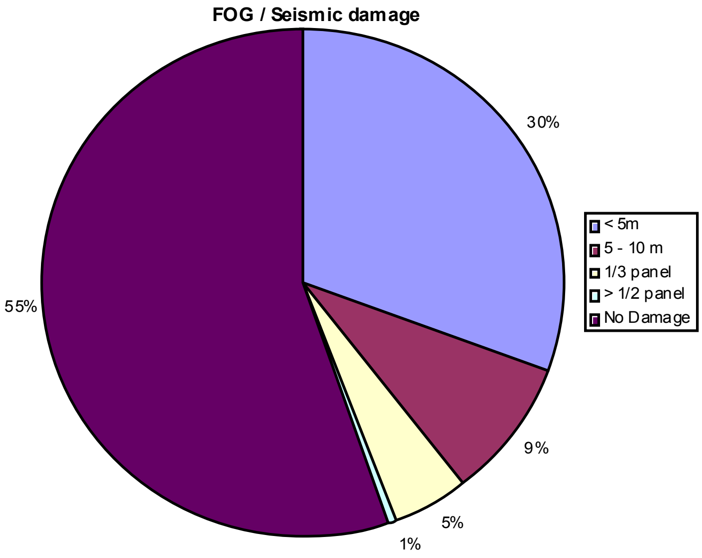


Figure 11: Damage results.

Rock related injuries statistics

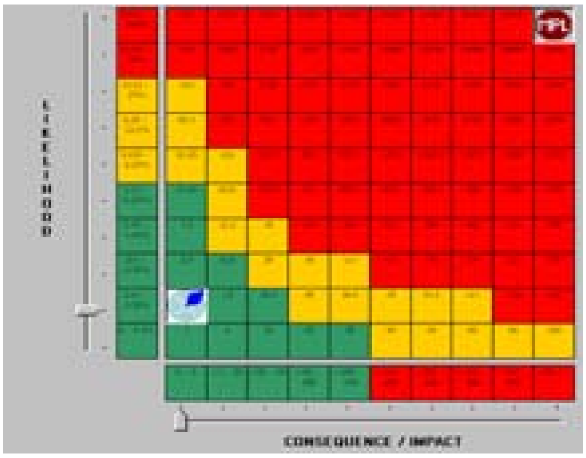


FIGURE 12 represents the risk footprint for the mine. It must be noted that fall of ground has an equivalent high likelihood and consequence. The manner in which both the likelihood and consequence can be managed and eventually be reduced is by establishing effective controls. The controls for fall of ground seismicity can be categorised as:

Likelihood controls: The controls that have been established by management to reduce the likelihood of a seismic event occurring. The mine design and layout address:

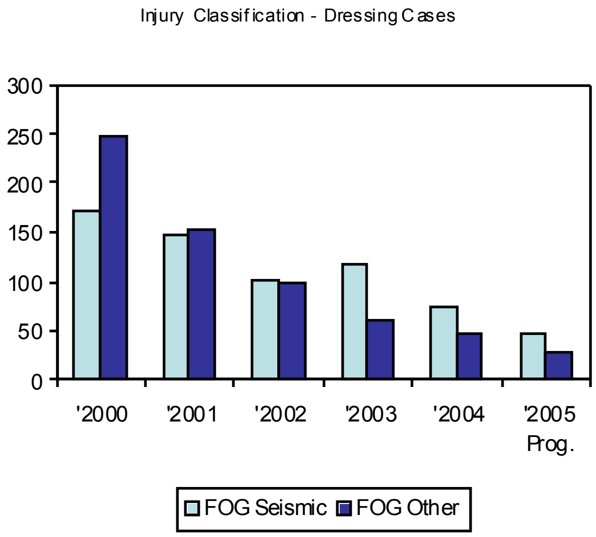
- Angle of approach
- Dip pillars
- Lead Lags
- Mining towards worked out areas
- Pillar bracketing
- Reduced mining spans
- Support design

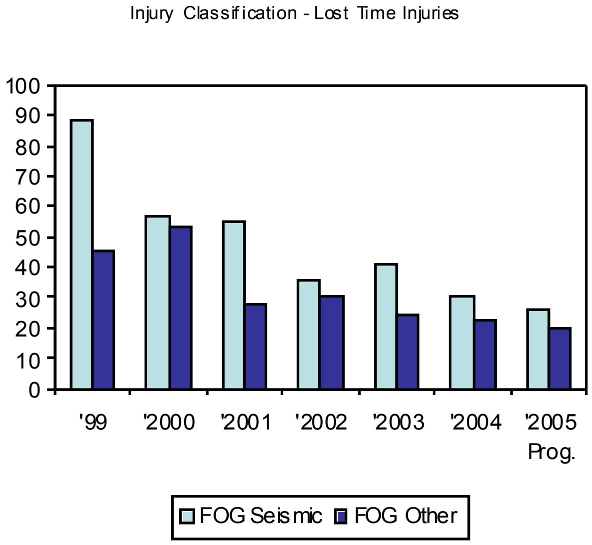
Consequence controls: The controls that have been established by management to reduce the severity of the event.

- Centralised blasting
- Pre-conditioning
- Seismic alert systems

Assuming 100% compliance for all controls as regards falls of ground seismicity would indicate the current status bar as having achieved the target set. This status would change on the consequence axis assuming all other controls have 100% compliance and pre-conditioning has zero compliance. This movement will not have any vertical affect which measures the likelihood. It is thus clear that the failure of pre-conditioning controls and the use thereof would influence the consequences of seismicity and therefore expose the organisation to a higher risk.

Improving the hangingwall and face conditions should ultimately have a positive effect on the safety of the people working in the area and the injury statistics.





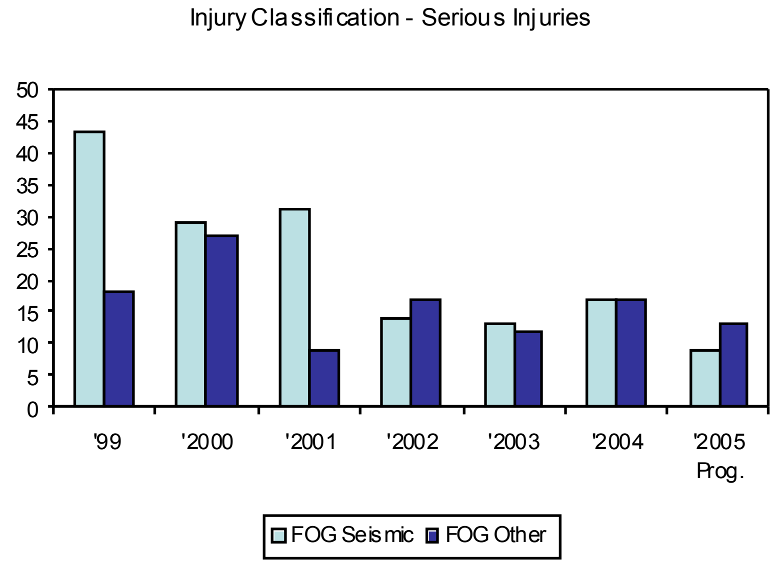


Figure 13 indicates the improvements in the injury rates since 1999.

As pre-conditioning is aimed at reducing the occurrence and effect of face bursting, the rock-related injuries are normalised against the number of damaging (M>0) on-shift events. An injury rate per 1000 damaging on-shift events is obtained. Since 2003 there was a marked reduction in the injury rate after a gradual increase up to the end of 2002.

Production

SIMRAC (GAP 336) indicated a decrease in the drilling times of the production holes but adding the drilling time of the pre-conditioning holes, there is an increase in total drilling time when drilling a 2.4 m long pre-conditioning hole. As the length of the pre-conditioning holes decrease, so do the total drilling times (Figure 14).

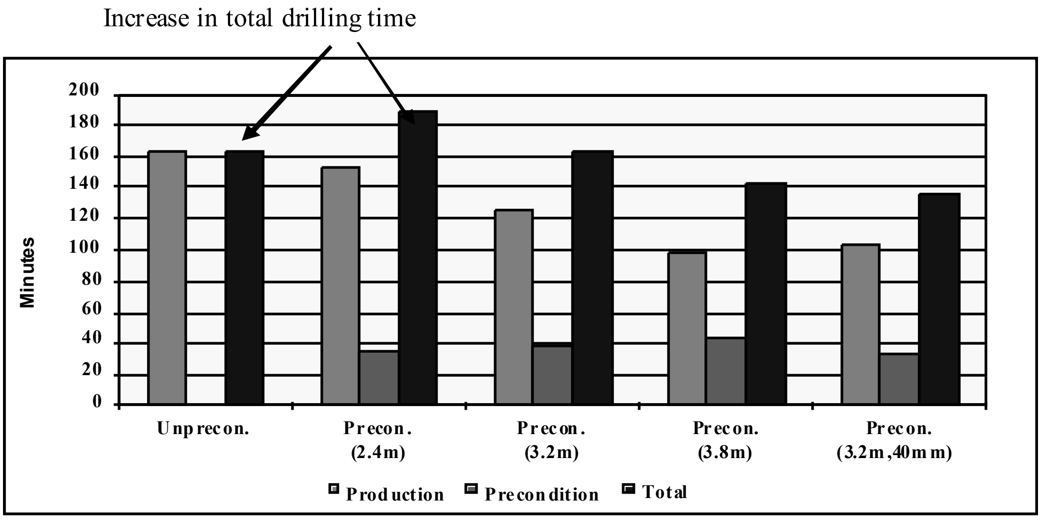


Figure: 14: Drilling times relative to the length of pre-conditioning holes.

As 2.4 m long pre-conditioning holes are drilled, with the increase in the drilling time, a decrease in production is expected. There is a noticeable increase in productivity during the past few years (Figure 15). The implementation of pre-conditioning therefore has had no negative effect on the productivity of Mponeng.

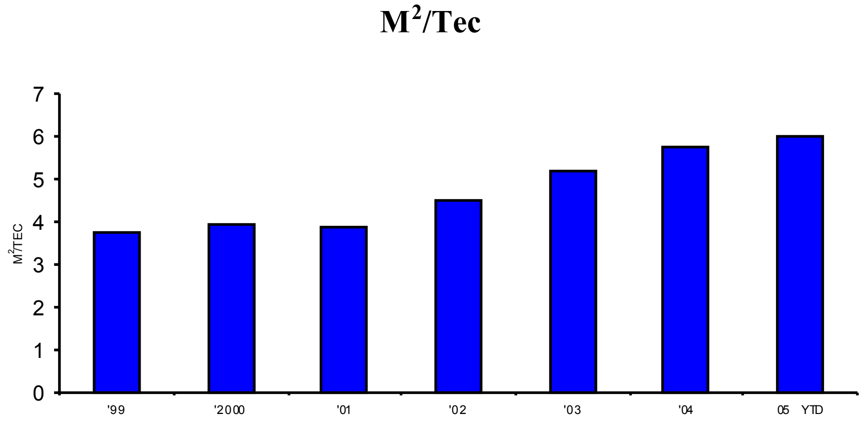


Figure 15: Square metres mined per total employee costed.

PEOPLE

The Mponeng philosophy for training our people and creating change is to break from the conventional thinking that organisational change must take place at the worker level. At Mponeng this mindset change has been established at the Exco, Mancom and Prodco levels to ensure that the required impact is realised. The initial training, commitment and communication have been established at the managerial level of the organisation. Once the accountability and responsibility has been established the introduction to the work force has really become a natural process. The thought being that the work force does not go underground not to produce safely but that managers and supervisors complicate and hamper good production by not empowering their crews and creating an environment in which people can produce their production targets safely every day.

The process involved the combination of skills or rather technical training and the ability to coach and empower teams and individuals to do the right stuff. Training was not only provided to production officials but all the services disciplines associated with creating a daily safe blast.

In creating this involvement the awareness levels increased and it ensured an overall support base for the introduction of pre-conditioning as a way of life. In order to get alignment, the design and synchronisation of the communication model and the safety management system was crucial as this ensured a further spread of the concept to organised labour and to the overriding principle that "No person comes to work at Mponeng to be injured". With the principle properly entrenched at this level, the introduction to the work force as mentioned previously was just good process.

A key element however, was that there is an additional bonus attached to the people responsible for making the concept work. The average payment as an integral part of the bonus system accounts for 6% of the total production pay-out. The introduction of this was not as a Big Bang approach but each crew being given its own personal attention with the initial training programme covering a three day period. The first day on surface covering general rock engineering principals, the second visiting two areas, one being pre-conditioning and the other not. The third day is spent in their own working place. This however we discovered needed to be extended to the first three blasts as the benefits of change-over to pre-conditioning is only evident after the second blast and in fact most problems initially are created because of this introduction into a high stress zone. The drilling, cleaning of holes and charging up in this condition is much more difficult in this high stress zone and many failures would happen in these first days. Practice has however shown that the whole application into a face will change the stress conditions as quickly as within the first two blasts.

The importance of doing follow-up training cannot be over emphasized. This follow-up and enforcement is supported by the introduction of observers in addition to the routine work done by line, safety and training officers. The observers are selected from the learner miner ranks. They are responsible to do daily observations and record compliance to standards. These observations form part of the Mponeng safety strategy and the main focus remains to change the behaviour and attitude of the individual and team to the fact that "No person comes to Mponeng to be injured". Using the learner miners for this function equips them to improve their ability to identify hazards, do observations using the SMAT technique and how to coach people in the correct way of rectifying the conditions or specific hazard. The importance of influencing behaviour and having a solid communication model cannot be over emphasized.

Conclusion

Since the implementation of pre-conditioning as a part of the overall seismic and support strategy, there has been a decrease in the occurrence of face bursting during the shift. At the same time the number of injuries associated with the seismicity has reduced significantly. These two key factors had no negative impact on productivity, in fact there has been noticeable improvements in the mining cycle. This is attributable to the physical conditions that are created by the implementation and correct use of pre-conditioning as a tool to reduce the occurrence and effect of face bursting. When the next generation goes deeper and further they can do it with confidence provided that they use the tool that have contributed to changing the working front of deep level mining.

Acknowledgements

Thank you to the management of Anglogold Ashanti for permission to publish this paper.

References

McGILL R.B. Strategies to manage seismicity in a deep VCR environment. Second International Seminar on Deep and High Stress Mining, SAIMM, Johannesburg, February 2004.

ROUX, A.J.A, LEERMAN, E.R & DENKHAUS, H.G. 1957. De-stressing a means of ameliorating rockburst conditions. Part 1 – The concept of de-stressing and the results obtained from its application J.S. Afr Inst of Mining and Met. October 101 – 119.

SIMRAC Project GAP 030. Preconditioning to reduce the incidence of face bursts in highly stressed faces, 1996

SIMRAC Project GAP 336. Develop and implement preconditioning techniques to control face ejection rockbursts for safer mining in seismically hazardous areas, 1998

SIMRAC Project GAP 811. Criteria for preconditioning at varying stoping widths in different geotechnical areas, 2003.