fracture length around an advancing stope as derived from a viscoplastic model is shown by a dotted line and the cumulative number of the recorded seismic events subsequent to the production blast is shown by a dashed line. It was also noted that the preconditioning blast, which is shown by a solid line, exhibited a similar decay in seismicity to the face blast, even though there was no change in stope geometry. It must be noted that the vertical axis of this plot has arbitrary units.

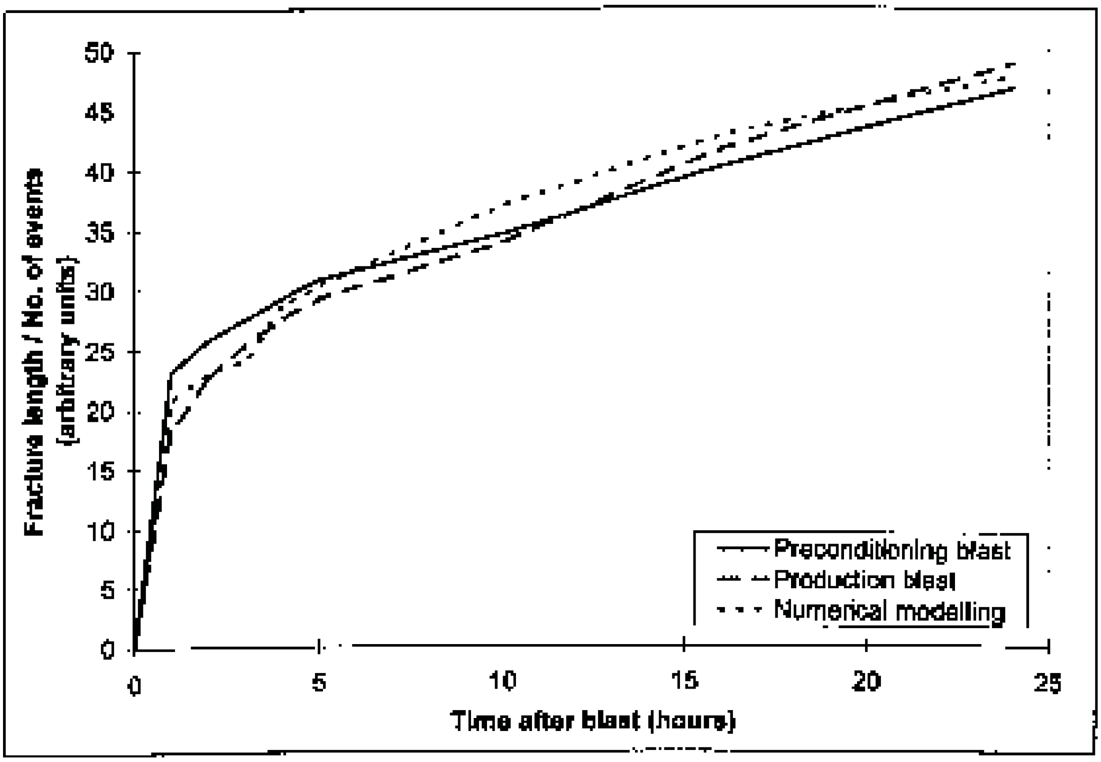

Figure 6.2.5 Comparison of total fracture length derived from a model with actual recorded seismicity subsequent to blasting (after Malan and Spottiswoode, 1997)

As stated above, the process of rockmass deformation near the stope face must be reflected in the rockmass response in the stope itself. Convergence recorded following a blast should reflect the time-dependent effects of the fracture zone. When the discontinuities generated within the model were subjected to a time-dependent decay in the cohesive strength, the convergence resulting from several mining steps approximated the response recorded from within the stope (Figure 6.2.6). The convergence profile of five mining steps as determined by a viscoplastic model is shown as a solid line, and the convergence profile obtained from actual measurements at the project site is depicted as a dotted line. During the period of measurements only two production blasts took place. It can be seen that a good correlation exists between the modelled and actual convergence profiles both before and after a face advance. In addition, it was also shown that a relatively large seismic event (M=1.1) near the face resulted in a similar trend in the convergence profile.

The continued convergence recorded some time after the blast as shown in Figure 6.2.6 could be an indicator of the degree of strain-energy accumulation within the rockmass. If this is the case, time-dependent responses could be used to "predict" anomalous rockmass behaviour, which could be an indication of the necessity to precondition a particular production face.

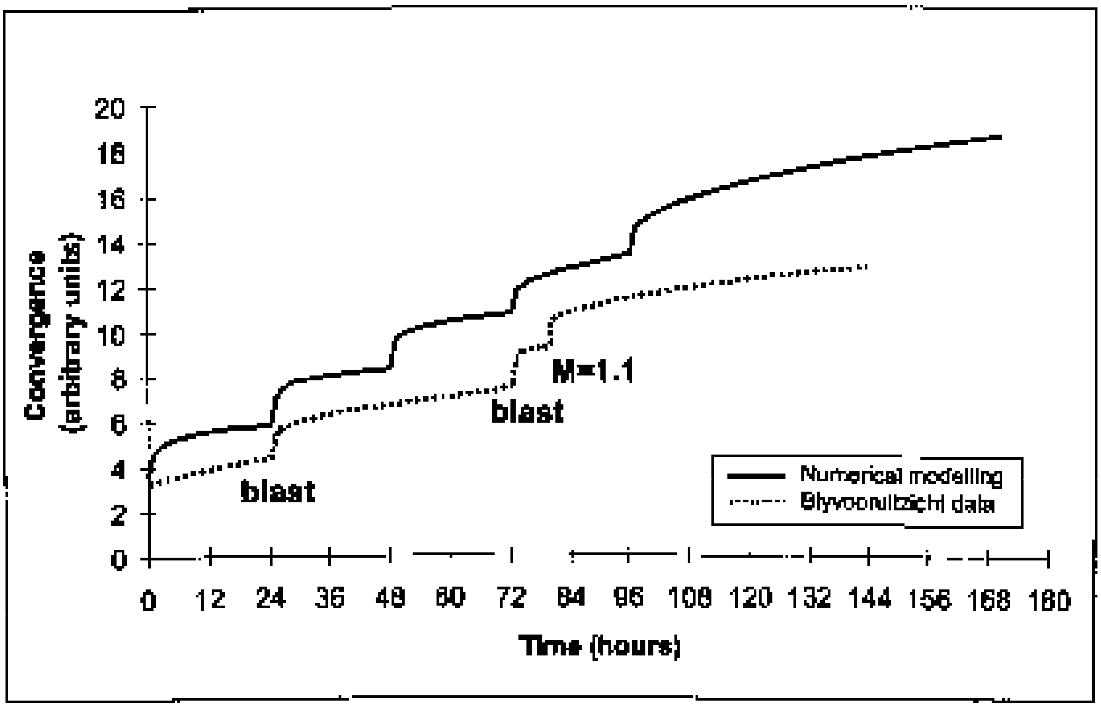

Figure 6.2.6 Comparison of modelled to actual convergence profiles

The usual convergence / ride measurements (Piper and Gürtunca, 1987) are termed "long-period measurements", as these are obtained by taking daily convergence readings with typically a 24-hour interval between successive data points. The profile of these convergence plots is the result of both the geometrical change in the excavation as the face moves away from the measuring instrument and the time-dependent behaviour of the rock. The true time-dependent behaviour of the rock can be identified by using convergence instruments such as clockwork convergence meters recording in a continuous fashion. Typical continuous convergence results obtained for a VCR stope panel are illustrated in Figure 6.2.7.

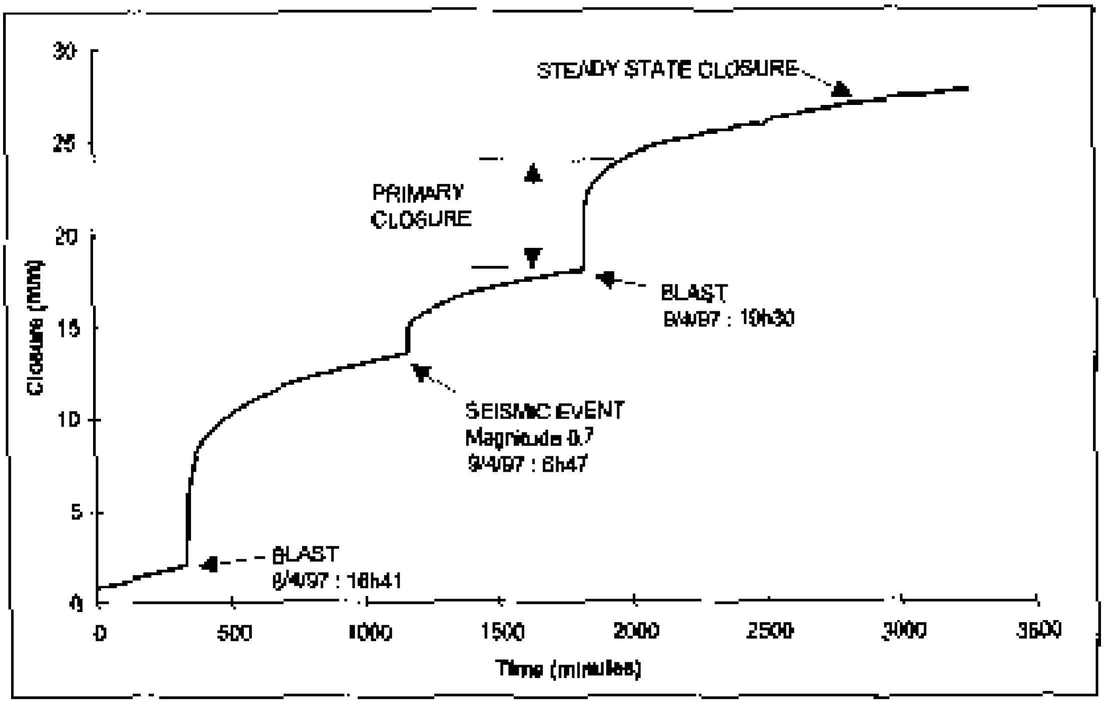

Figure 6.2.7 Typical time-dependent convergence data measured with an instrument that records in a continuous fashion (after Malan, 1998)

Note that there is a primary convergence phase including an instantaneous increase at blasting time, followed by the steady-state convergence phase. This detailed information is lost if only daily measurements are taken. In stopes where VCR is mined with hard lava in the hangingwall, the instantaneous convergence at blasting is prominent and forms a significant portion of the daily convergence. However, Malan (1998) also found that the instantaneous convergence at blasting time decreases as the distance from the face to the measuring instrument increases. With sufficient distance from the face, it may disappear entirely. The relationship between continuous and daily measurements is illustrated in Figure 6.2.8. Note that the instantaneous convergence at blasting time decreases as the distance to face increases. However, these profiles are not real data, but were generated from an analytical time-dependent convergence model.

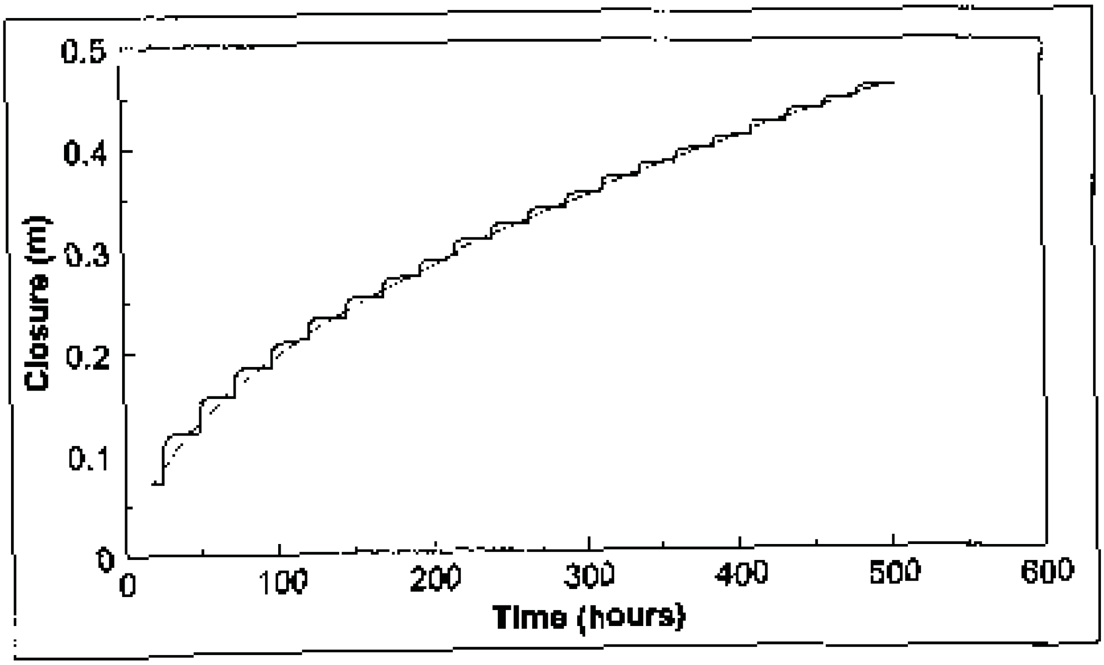

Figure 6.2.8 Relationship between continuous (solid line) and daily (dotted line) convergence measurements (after Malan, 1998)

Of importance to preconditioning is the indication from this preliminary study (Malan, 1998) that, for areas prone to face bursting, the instantaneous response close to the face is very large, while the steady-state convergence rate following this is small. In areas where the risk of face bursting is low, it appears that the instantaneous response is small, followed by a high steady-state convergence rate. These measurements could, therefore, be developed into a measure to identify areas where preconditioning should be applied. It should, however, be emphasised again that further work is necessary if this hypothesis is to be proved.

Modelling has indicated that the instantaneous convergence response is the result of the instantaneous stress redistribution following a mining increment. For stopes that are considered prone to face bursting and that have a high stress peak close to the face, there is a large redistribution of stress after blasting and, therefore, a significant instantaneous convergence response. For stopes where the stress is low in the face area, the instantaneous response is small. High steady-state convergence rates, on the other hand, indicate a greater mobility of the rockmass, which results in the stored strain energy in the face area being dissipated in a non-violent manner.

Although no continuous convergence data was collected for the preconditioning panels at the project site, there was an increase in the convergence rate as soon as preconditioning was initiated. It is speculated that this increase is due to both an increase in the instantaneous response at blasting time and an increase in the steady-state convergence rate. The instantaneous response is expected to be larger, as a larger stress transfer will take place because of a larger volume of rock ahead of the face being affected by the preconditioning.

6.2.4 The effect of preconditioning on stress-wave transmission through discontinuous rock

Underground observations have indicated that preconditioned stopes are generally less prone to damage caused by seismic events occurring at some distance away from the stope face. A possible mechanism contributing towards the reduction in damage is associated with the extension of the fracture zone as well as existing discontinuities being mobilised by the preconditioning blasts.

Stress waves are initiated by the sudden rupture of fault and dyke interfaces, and propagate towards the stope. In homogeneous, intact rock the amplitudes of the stress waves attenuate in inverse proportion to the distance propagated. This is called geometric attenuation. In discontinuous rock, however, the incident wave energy is reflected and refracted at the discontinuity interfaces. The amplitude of the stress wave that interacts with the excavation surface is thus significantly reduced in amplitude due to geometric attenuation, as well as energy reflection. In a highly discontinuous rockmass more energy is reflected and the refracted portion that is finally transmitted to the excavation surface is reduced in magnitude.

Daehnke (1997) investigated the reflection and refraction characteristics of various discontinuity types. A non-cohesive frictional interface model was used to investigate the wave interaction with rockmass discontinuities ahead of the stope face. However, Daehnke's (1997) analysis of a linear spring model is invalid in the case of frictional contact since the problem is non-linear and cannot be analysed by simple superposition of harmonic waveforms.

Preconditioning blasts generate new fractures in the reef horizon and mobilise and extend the existing discontinuities ahead of the stope face and, hence, compared to non–preconditioned stopes, the excavation is more effectively shielded to incident stress waves. This results in reduced peak particle velocities in the immediate vicinity of the excavation, and potentially less structural damage to the rockmass.

6.2.5 Postulated preconditioning mechanism

The stress fields and gas pressures generated by preconditioning blasts remobilise the blocks defined by mining-induced fractures by shearing through asperities that are responsible for the "lock-ups" on the fractures. In the process, strain energy release is facilitated by the stable sliding of blocks past each other, and the risk of occurrence of face bursting during the production shift is reduced. Preconditioning results in the redistribution of stress away from the working face, and, thus, in the reduction of a faceburst. This is shown in Figure 6.2.9. A preconditioning blast, through remobilisation of fractures and non-violent release of strain energy on these fractures, generates a destressed zone ahead of the face. The resulting less stressed ground is then also less likely to allow sudden slip on existing fractures and / or breakage on asperities when excited by incoming stress waves from distant events. In this way, a cushion zone is generated and it becomes possible to minimise the extent and severity of damage that may occur as a result of distant events.

A preconditioning blast normally generates a very localised crushed zone of rock surrounding the blasthole. The size of this zone is dependent on the rockmass characteristics, stress state, blasthole diameter and the type and amount of explosive. Surrounding this crushed zone, an outer fractured zone where blast-induced radial fractures occur is also generated. It was observed that this zone is normally limited to the region between the hangingwall and the footwall (i.e. reef horizon). The greatest effect of preconditioning in terms of remobilisation of existing fractures happens within and some distance beyond this zone.

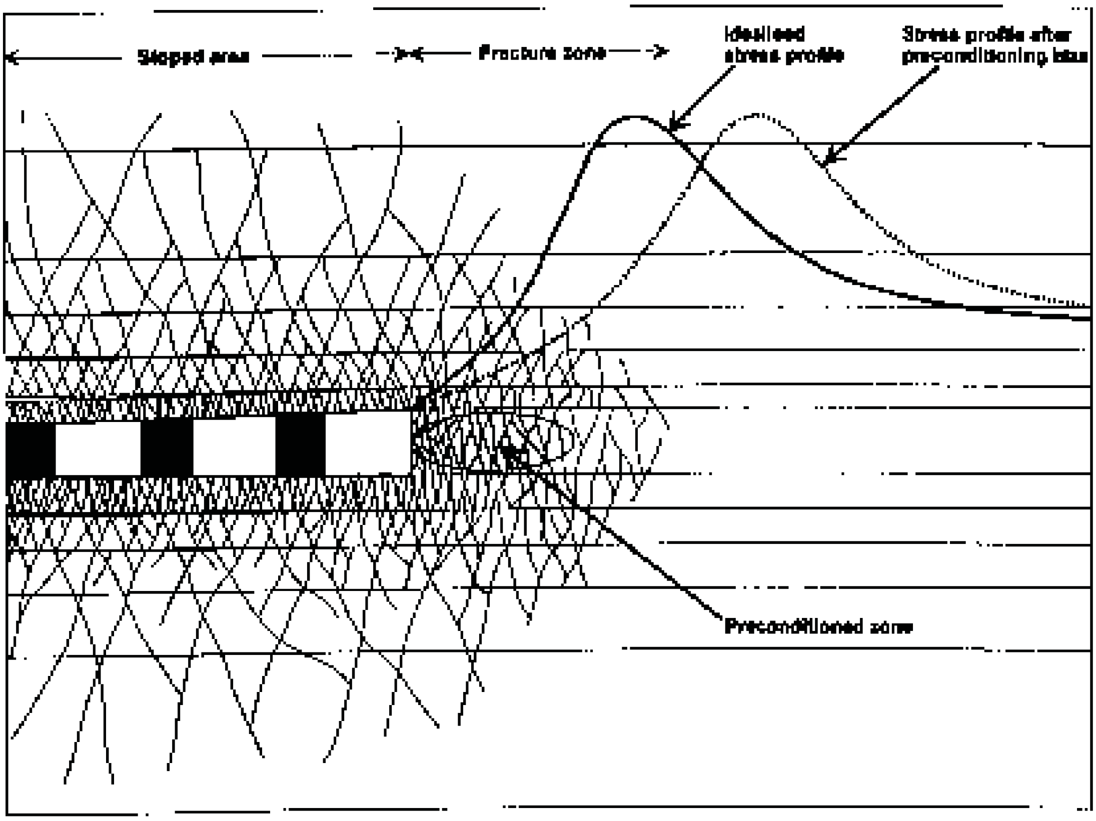

Figure 6.2.9 Stress redistribution brought about by preconditioning

Preconditioning changes the state of stress on the rockmass, as well as physically softening it in the immediate area surrounding the blasthole. However, it is likely that, if the confinement were to be re-established in a previously preconditioned zone, the preconditioning effect could be reversed. It has been shown, both by underground observation and by computer simulation, that this is possible. Under certain circumstances, it is possible that stress can be transferred back towards the face area. This could happen either through the effects of large seismic events near the face, or of poorly positioned preconditioning holes, or through the regeneration of lock-ups due to time-dependent deformation of the rockmass.

If the mechanism of preconditioning was only one of new fracture generation one would expect to find new fracture groups in the hangingwall of the preconditioned panels. However, on the basis of the findings from the previous chapter, no new fracture groups were found to occur in the hangingwall of the preconditioned panels but very localised blast-induced fracturing was observed around the preconditioning holes in the reef plane. So, the most likely mechanism of preconditioning is the extension of and the causing of slip on pre-existing fractures. There is evidence of re-activation of pre-existing fracture surfaces in the preconditioned panels.

The shake-up of the rockmass and the gas produced as a result of the blast are two ways in which the preconditioning blast actually causes slip on the fracture surfaces. The shake-up of the rockmass as a result of the blast could allow previously jammed asperities or lock-up points in the jointed rockmass to slip, allowing for further slip across the whole fracture. The gas produced by the blast penetrates through the fractures at high pressure, reducing the effective stress acting across the fractures and, even, propping them open. This could allow shear across previously jammed asperities and enable slip on larger areas of the fracture surface. Slip of fractures due to gas is believed to be the dominant preconditioning mechanism and, therefore, a high-gas-generating explosive would most effectively precondition the rockmass.

In order to dissipate strain energy by enhancing shear mobilisation of the discontinuities and the breaking of asperities, the mechanism of preconditioning is one of opening up pre-existing fractures ahead of the stope face. In the process, blast gases can also penetrate and separate the distinct bedding planes that overlie many reefs. Any fractures that have a tendency to grow in the preconditioned zone will not be able to penetrate this weakened bedding plane. Under these circumstances production-blast fractures will truncate before they cause damage to the hangingwall.

The mechanics of preconditioning involve destressing the immediate rockmass as a result of local stress transfer. Local readjustments in the state of stress in the zone of fractured rockmass ahead of the face that has been subjected to the preconditioning process result in the stress being shifted to adjacent areas of the rockmass outside the direct influence of the preconditioning blast. The benefit of this process to the mining personnel is that a low-stressed area of rock is produced in the immediate stope face. The high stress in the immediate face that can result in facebursts is no longer present and hence the potential for face bursting is drastically reduced.

As the mechanism of preconditioning is one of stress transfer resulting from induced deformations in the fracture zone ahead of the face, rather than one of actually modifying the material properties of the rock, the zone that is preconditioned is still capable of carrying high loads. After a panel face has been preconditioned, it is possible that subsequent mining of that face or of adjacent faces will result in the transfer of stress back onto the preconditioned rockmass, if nothing is done to prevent this from happening. Thus, the effect of preconditioning is localised both in space and time.

The stress is redistributed in the rockmass in response to both mining and preconditioning and this stress transfer is a dynamic, ongoing process. The preconditioning process must be integrated into the production cycle in a controlled, sequential manner. This sequence must be engineered to ensure that the most favourable stress distribution for maximum face stability is maintained at all times. In the case of face-parallel preconditioning, this means that the order of preconditioning must be sequential, from the lagging to the leading panel. In the case of face-perpendicular preconditioning, the preconditioning blast must be maintained as an integral part of the production blast.

Despite the assertion that the effects of preconditioning are local, it has been seen that preconditioning occasionally has a more widespread effect when large events occur subsequent to a preconditioning blast. The most likely cause of these large events either immediately after a preconditioning blast or some time later is related to the stress transfer occurring in the rockmass. The preconditioning blast initiates the immediate transfer of stress from the preconditioned rock onto the adjacent rockmass. If this adjacent rockmass is already highly stressed and in a condition of unstable equilibrium, it will also undergo a phase of readjustment. This readjustment results in a further stress transfer onto other adjacent rock. This process can propagate through the rockmass in a form of "chain-reaction" as local zones of rock readjust and re-equilibrate. Ultimately, the system as a whole must once again reach a state of equilibrium but, if in the course of this transition to a new state of equilibrium a large local instability is encountered, then a large seismic event can be initiated or triggered.

6.3 Summary

There are two mechanisms by means of which the preconditioning blast actually causes slip on the fracture surfaces. The first mechanism involves the shake-up of the rockmass as a result of the blast. This could allow previously jammed asperities or lock-up points in the jointed rockmass to slip, allowing for further slip across the whole fracture. The second would involve the penetration of the gas produced by the blast through the fractures at high pressure, reducing the effective stress acting across the fractures and even propping them open. This could allow shear across previously jammed asperities and enable slip on larger areas of the fracture surface. Preconditioning involves both of these mechanisms.

The mechanism of preconditioning is one of opening up pre-existing fractures ahead of the stope face so as to dissipate strain energy by enhancing shear mobilisation of the discontinuities and the breaking of asperities. In the process blast gases can also penetrate the distinct bedding plane that overlies many reefs, weakening or even delaminating this plane. Any fractures that have a tendency to grow in the preconditioned zone will not be able to penetrate this weakened bedding plane. Under these circumstances, production-blast fractures will truncate before they cause damage to the hangingwall.

The mechanics of preconditioning involve the destressing of the immediate rockmass as a result of local stress transfer. Local readjustments in the state of stress in the zone of fractured rockmass ahead of the face that is subjected to the preconditioning process result in the over-burden load being shifted to adjacent areas of the rockmass outside the direct influence of the preconditioning blast. The lowered levels of stress in the immediate face means that the incidence of face bursting is drastically reduced.

The effect of preconditioning is localised both in space and time. As the mechanism of preconditioning is one of stress transfer (resulting from induced deformations in the fracture zone ahead of the face), rather than one in which the material properties of the rock are modified, the zone that is preconditioned is still capable of carrying high loads. After a panel face has been preconditioned it is possible that subsequent mining of that face or of adjacent faces will result in the transfer of stress back onto the preconditioned rockmass.

Of practical significance is the fact that stress transfer is a dynamic and ongoing process. The stress is redistributed in the rockmass in response to both mining and preconditioning. For this reason, the preconditioning process must be integrated into the production cycle in a controlled sequential manner. This sequence must be engineered to ensure that the most favourable stress distribution for maximum face stability is maintained at all times.

7 IMPLEMENTATION OF PRECONDITIONING

7.1 Introduction

After the successful implementation of preconditioning at research sites and the completion of a comprehensive monitoring programme, the project team was assigned to investigate and formulate the best implementation procedure for preconditioning. The main task of this broadly defined assignment was to investigate the feasibility of forming an implementation team that could provide assistance with respect to the proper implementation of preconditioning and the training of personnel on individual mines. In order to achieve this aim, the set out below, in point form, was adopted.

- The applicability of preconditioning as an implementable production technique was assessed.
- The knowledge that needs to be transferred to industry for the successful implementation of preconditioning was identified.
- The best way to enable this knowledge transfer was determined.
- The nature of the team required to successfully transfer the knowledge and implement the preconditioning was identified.
- The implementation team was appointed.
- The potential implementation sites in the industry were identified.
- Field trials on suitable mines were initiated.
- Regular audits were conducted to ensure the proper implementation of preconditioning.

Prior to the initiation of this task, research results were communicated mainly to the rock mechanics community in the South African gold mining industry by means of seminars in which interactive discussions were encouraged. Since the research results were very positive, discussions concentrated mainly on the implementation issues themselves.

7.2 Implementation experiments

During the face-perpendicular preconditioning experiment at the project site at Mponeng gold mine the initial encouraging results became common knowledge among members of the production team. Subsequently, the project team was asked to help implement the technique at a few other stopes, initially at the same mine and then at a few other mines. The level of confidence in the results obtained from the research site grew, as similar results were achieved at other implementation sites. In addition, greater experience of various aspects of the implementation of preconditioning was gained.

The training needs of the underground personnel responsible for the correct implementation of preconditioning were then determined. A private consulting company "Schuitema Associates" was contracted to carry out interviews with mining personnel to assess their attitudes towards safety in seismically active areas and the role of preconditioning in improving safety. The consultants also assisted in evaluating the mining personnel's views on the methods of training that would best facilitate the effective implementation of preconditioning on the mines. The survey was conducted at the project site after the preconditioning experiment had been running for some time. It revealed a prevailing attitude that later contributed to the demise of the application of preconditioning at that site. While the workers acknowledged the improvement in underground conditions that the introduction of preconditioning had brought about, they were unwilling to do the preconditioning without extra pay for their efforts. The results from this exercise have formed an integral part of the process of knowledge transfer to the mining industry.

When these more recent findings and the current understanding of preconditioning were communicated to the mining industry via a number of seminars, the response was positive. Subsequently, several mines have started preconditioning under various mining conditions. The project team has been approached on several occasions by individual mines for advice concerning the technique and its applicability to their particular situation and for input to ensure that preconditioning is being implemented appropriately. Consequently, the project team has been involved in a number of implementation activities on various mines. A few examples are given below.

Case example 1

The project team was contacted by the rock mechanics department of a mine and asked to help implement face-perpendicular preconditioning at a particular panel of a VCR stope at which serious faceburst problems were being experienced. The actual implementation of preconditioning was initiated after limited underground training of the workers. A week later it was reported that a preconditioning blast had triggered a seismic event that resulted in a fatality and some degree of damage to the workings. Following an investigation it was found that the incident had happened a few panels below the preconditioned panel. The seismic event had occurred within seconds of the initiation of the preconditioning blast in a panel above.

Enqueries as to the reasons for the early initiation of the preconditioning blast or the presence of workers in the same stope during the blast were unanswered. Preconditioning was held responsible for the incident and it was abandoned at this site. The lack of education and training proved to be negative factors that counted against the implementation of preconditioning at this site.

Case example 2

Preliminary training exercises had been carried out on a mine at the request of mine management. While the training was being carried out, the senior production personnel had initiated preconditioning without the involvement of the project team and with considerable success. What prompted the mine to undertake preconditioning was several days of face bursting in the geologically complex area. After the introduction of face-perpendicular preconditioning no rockburst damage of any kind was reported.

In order to investigate how the mine implemented the preconditioning and to see the results the project team visited the site. During this visit it was found that preconditioning was not routinely carried out at some parts of the stope and this was immediately reflected in the condition of the hangingwall. The results of these observations were discussed with all production personnel involved. A discussion session in the training centre with the entire stope crew on the use of preconditioning proved extremely useful to the understanding of the issues surrounding its implementation.

Case example 3

Owing to the greater interest in and usage of preconditioning at Mponeng gold mine, where the face-perpendicular preconditioning technique was tested, a broader approach was adopted for technology transfer and the implementation of the technique. Training sessions were conducted with all safety officers and training centre personnel to make them aware of the technique, the basic theory, the benefits and how to evaluate the effectiveness of these preconditioning blasts from the visible effects on the production face.

While adequate training took place at this project site the education of workers was not adequately carried out and, therefore, the preconception that preconditioning represented extra work could not be changed within the workforce. Payment for this supposed extra work became an issue that led to the preconditioning being discontinued when the project team was withdrawn from the site.

At another stope in the same mine, the implementation of face-perpendicular preconditioning was initiated by production personnel headed by a section shift boss. Very good results, similar to those from the project site, were reported from this site. The project team visited the site several times and observed that stope panels were regularly preconditioned. The section shift boss was routinely following up the whole process. At a later stage, the production team managed to mine a 20 m wide up-dip panel, under the guidance of the project team, through a highly stressed strike stabilising pillar, without any incidents. This was mainly the result of properly implemented regular face-perpendicular preconditioning.

Case example 4

This mine had been experiencing difficulties when mining in the vicinity of seismically active geological features such as faults and dykes. While the problematic stoping areas were mainly remnants, the difficulty of integrating face-parallel preconditioning into the production cycle meant that the mine was more interested in attempting to apply face-perpendicular preconditioning to the remnant areas. However, at that stage the effectiveness of face-perpendicular preconditioning in those mining environments was unknown. Another interesting question related to the direct application of preconditioning to seismically active geological features rather than to the stope faces. Previous experience at a face-perpendicular preconditioning site had shown that face preconditioning could help to minimise the damage caused by seismicity located on geological discontinuities in the vicinity of the mining face. But, preconditioning such features directly had not been investigated. Therefore, it was recommended that preconditioning be used on the faces to minimise the damage caused by seismicity associated with the geological features, as well as to prevent facebursts caused by high face stresses.

Case example 5

The majority of this mine's production comes from secondary mining by pillar extraction, as very limited ground is available for primary mining. Thus, face-parallel preconditioning was recommended in order to minimise the faceburst risk associated with pillar extraction. However, the management team of this mine was more interested in face-perpendicular preconditioning and the possibility of implementing this in a pillar-extraction environment. Production personnel and the rock mechanics department resisted implementing face-parallel preconditioning because of the difficulty of fitting it into the mining cycle. A related reason for being more interested in face-perpendicular preconditioning was that the effect of increasing the face advance rate had, by this time, been quantified for this method. Although there is no reason that face-parallel preconditioning should not have a similar effect on face advance rate, this had not been quantified.

Following the discussions with mine management and the rock mechanics department, it was decided to implement face-perpendicular preconditioning in two different pillar-extraction areas, with very limited involvement of the preconditioning project team. Some time later, the rock mechanics department reported that preconditioning had been implemented successfully at one site by production personnel, but that the project team's involvement was required at the other site. This second site was visited by the project team, together with production and rock mechanics personnel.

At this site, there are a series of dip pillars, which were left behind after sequential grid mining took place between two faults, as shown in Figure 7.2.1. The fault located at the upper boundary of the dip pillars is seismically very active and has historically caused damaging events. The other fault situated at the lower boundary is seismically inactive, probably because the down-dip side of the fault is still unmined. The intention was to mine these dip pillars one at a time, reducing the hazard by using face-perpendicular preconditioning and by leaving bracket pillars at both the up-dip and down-dip ends of each dip pillar. The mining activity was carried out by advancing a breast panel through the pillar, with a gully on the down-dip side of the face, as shown in Figure 7.2.1. Although the physical conditions of the face and hangingwall were satisfactory at the time of the first visit, the preconditioning project team expressed concern about breast mining under those conditions.

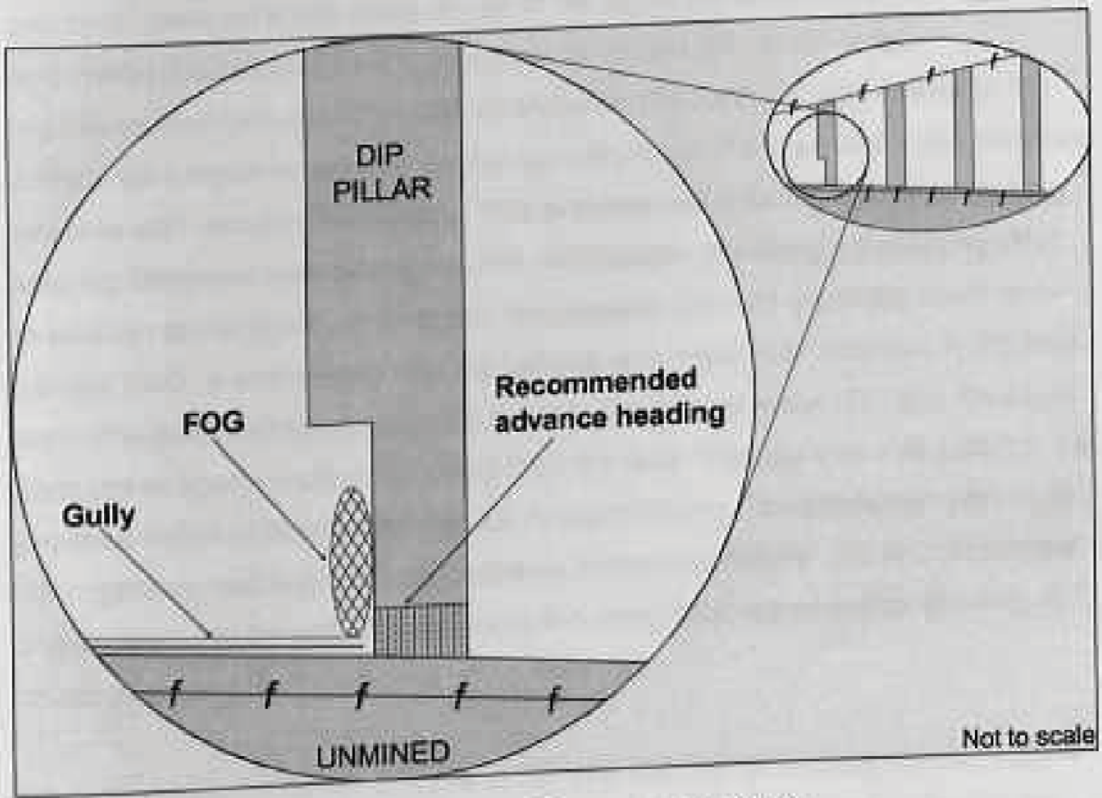

Figure 7.2.1 Implementation site (Case example 5)

The site was revisited a few days later and extensive falls of ground (FOG) in the face area were observed (at the position indicated in Figure 7.2.1) which had occurred after the first visit to the site. This confirmed the concerns of the preconditioning project team with respect to the breast mining in this scenario. It was recommended that the advancing breast panel be stopped and a wide (~10 m) advance heading be mined together with the gully. The mining of up-dip panels should be started once the proposed advance heading holes into the other side of the pillar. It was also suggested that implementing preconditioning on the breast panel would probably help to improve the situation, but would not solve the actual problem, which was directly related to the mining configuration. It was stated that the project team would not be interested in implementing preconditioning in view of the layout that existed, but would assist if an up-dip mining layout was used. This particular implementation was never carried out.

Case example 6

At this mine the management decided to implement face-perpendicular preconditioning on a trial basis at one of the faceburst-prone sites on the mine and invited the preconditioning project team to take part in the initial implementation process. The site, as shown in Figure 7.2.2, was visited by the project team together with the production personnel. Panels I and II had high face stresses with resultant facebursts. This problem had arisen because of the long lead-lag distances associated with the early stages of cutting a stabilising pillar. In addition to the faceburst problem, hangingwall fall-outs associated with face-parallel shallow and steeply dipping fracture sets were quite common in the face area. The shallow fractures dipped towards the face at about 20°, and the steep fractures at approximately 70° away from the face. The site was well suited to the implementation of face-perpendicular preconditioning. The production personnel, although they had only minimal exposure to preconditioning, showed an interest and appeared to be enthusiastic about the immediate use of preconditioning as an aid to solving their problems at the site.

While the implementation process at this site seemed to be progressing and the preconditioning project team was preparing for another training session for the stope crew, there were some changes in the management structure of this mine. Ultimately, while the new mine management was apparently in favour of the implementation of preconditioning at this mine, it was decided to postpone the preconditioning activity to an indefinite date.

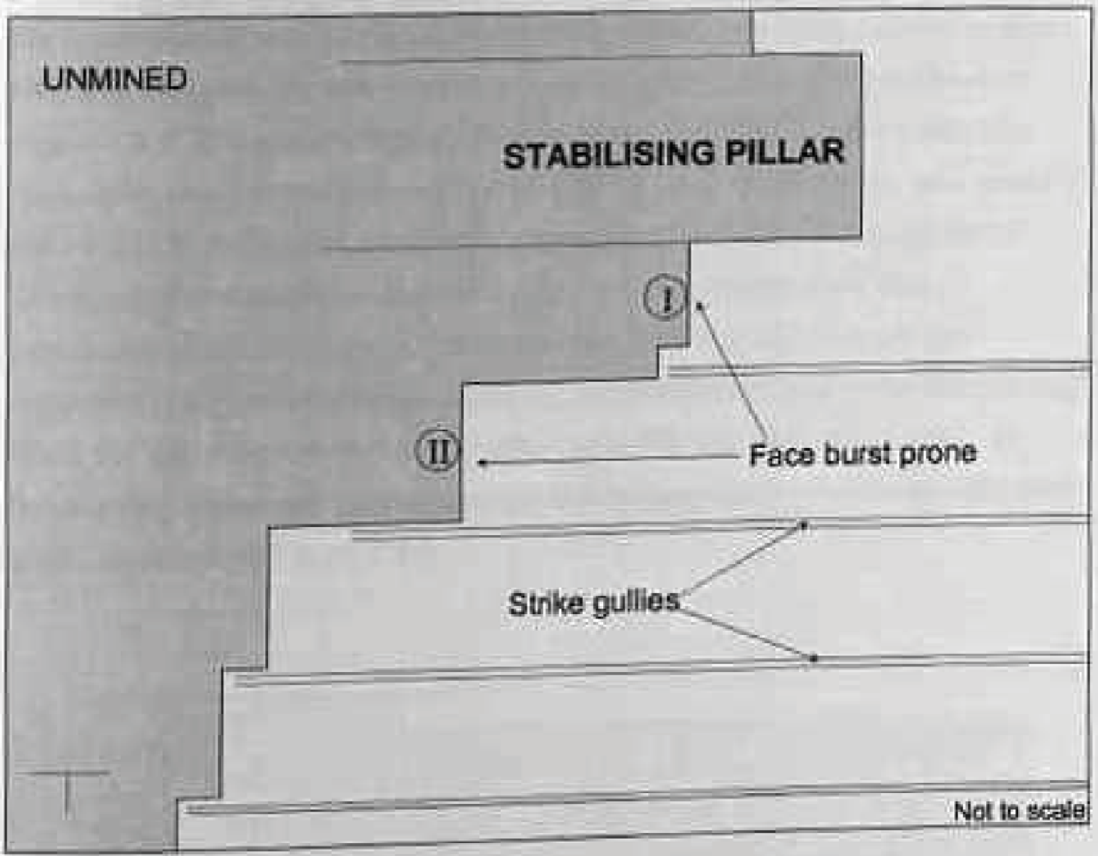

Figure 7.2.2 Implementation site (Case example 6)

Case example 7

At this mine, an attempt had been made to implement preconditioning without consulting the preconditioning project team and the claim was made that preconditioning was not effective. The project team became involved at that site at a later stage of implementation and found that the preconditioning was being incorrectly applied; neither education nor training had been provided for the stope crew. It was also very difficult to change the stope crew's preconceptions about preconditioning at that late stage. However, some progress had been made in some parts of that site in teaching the correct application of preconditioning. Nevertheless, some time later, the mine management decided to terminate the implementation of preconditioning.

Case example 8

This mine's rock mechanics department implemented face-perpendicular preconditioning in one of their problematic areas. The intention was to minimise the occurrence of and damage caused by facebursts associated with foundation failure at the down-dip side of strike stabilising pillars. This layout is shown in Figure 7.2.3. The preconditioning project team was invited to hold a technical discussion only and not become involved in the implementation. As was stated by the mine rock mechanics personnel, a substantial reduction in the number of face-facebursts and resulting production losses had been noted since face-perpendicular preconditioning had been initiated at this site. The site had experienced a number of large damaging seismic events prior to preconditioning. Since the implementation of preconditioning at this site, only one incident of facebursting happened but the damage was concentrated in non-preconditioned areas, as shown in Figure 7.2.3.

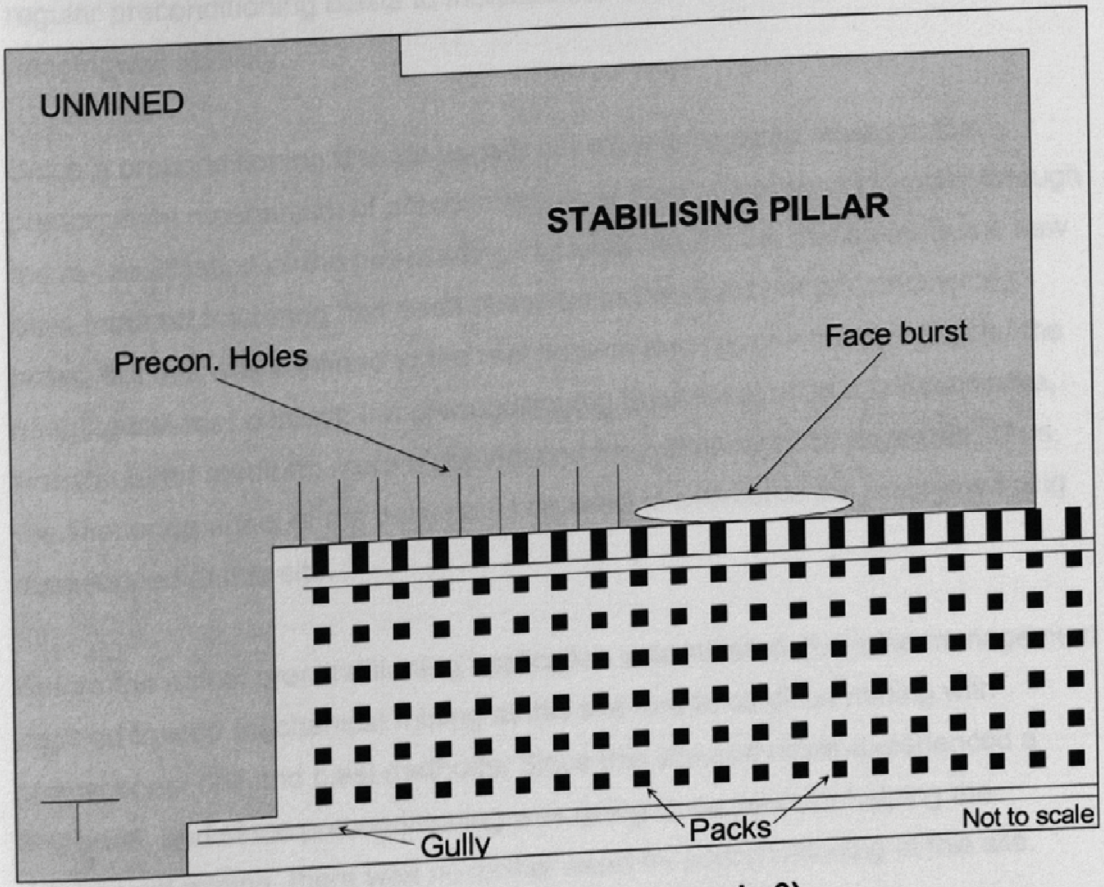

Figure 7.2.3 Implementation site (Case example 8)

Prior to this particular application, all previous preconditioning applications were done on a mining panel face. In this case, preconditioning was used to control faceburstlng in a stabilising pillar. It is still not clear how the effects of preconditioning carried out a few months earlier (furthest away from the panel face) could still be manifested. This seemed to contradict the time-dependent nature of the preconditioning effect. (The fact that the edge of the pillar is stationary might have a bearing on the apparently greater permanence of the preconditioning effect.)

Case example 9

This mine invited the preconditioning project team for an underground visit to a mechanical mining site and to discuss the possibilities of using preconditioning at that site. There was no faceburst problem at the site but the impact ripper was having difficulties breaking the hard footwall quartzite. In addition, a serious hangingwall-control problem was experienced at that site. The idea was to set off regular preconditioning blasts to increase the face advance rate and to improve hangingwall stability.

Since a preconditioning blast is usually set off in a fractured medium, the predominant mechanism of preconditioning is then one of stress transfer through the re-mobilisation of the pre-existing fractures around the blasthole. Some new blast-induced fracturing had been observed in the vicinity of preconditioning holes, but this was confined to the reef horizon and never extended beyond the hangingwall-reef contact. If a preconditioning blast is set off in a fairly massive, less fractured medium, more blast-induced fracturing might be expected. Thus, the shattering effect of the blast could be used to overcome the problems being experienced at this site.

Before the actual preconditioning application was initiated, the mine management decided to stop mechanical mining at this site and to continue mining with conventional drill and blast methods. Since this site had never experienced a faceburst, and since preconditioning was going to be used for helping the mechanical mining, there was no further need for preconditioning at this site.

Most recent cases of implementation

Subsequent to the completion of the research project, Kloof, Savuka and Tau Tona Gold Mines also implemented preconditioning at various stopes with the help of the project team. Tau Tona Gold Mine is testing the preconditioning technique in a shaft pillar area and planning to implement it in VCR stopes in the near future. Currently, Mponeng Gold Mine is implementing preconditioning at every stope as they have recently incorporated preconditioning in the mine's code of practice.

All remnant extractions in the Far West Rand region (e.g. Savuka, Kloof, Driefontein Consolidated, Placer Dome Western Area Joint Venture and Mponeng Gold Mines) are done using preconditioning blasting, while Harmony Gold Mine is implementing preconditioning in two of their shafts (2 and 3) in the Free State area. The majority (83%) of the Klerksdorp and Free State remnants are conventionally blasted (i.e. preconditioning is not used).

South Deep Gold Mine of Placer Dome Western Area Joint Venture has recently implemented preconditioning in one of the sections. During a visit to this site, the project team found the application of preconditioning to be sub-standard. The correct implementation procedure was described to the production personnel by the project team. The project team was then involved in ensuring correct implementation at this site, as well as another test site at the same mine.

A few years ago, the technique was implemented successfully in a development end at Kloof Gold Mine. A seismically active dyke was safely mined through by implementing a preconditioning technique. Prior to implementation, faceburstlng was a major concern in this area. A similar experiment was run in twin development ends at Driefontein Consolidated Gold Mine. The research team's role was to design and implement a layout for preconditioning holes as well as micro-seismic monitoring to assess the effectiveness of preconditioning and to determine the minimum re-entry time following a preconditioning blast. Despite a rockburst occurring as a result of a preconditioning blast triggering a pair of seismic events, no injuries to personnel occurred after preconditioning was implemented at this site.

7.3 Key issues in implementation

Much has been learnt through different levels of involvement in the implementation of preconditioning in different mining environments. The key issues determining the level of success in implementation are identified and listed below.

- **Fundamental understanding of the concept and the technique:** There is a general lack of understanding as to why there is a need for preconditioning, and which problems are addressed through the implementation of this technique. In addition, it has been found that "how the technique works" is not fully understood. If the answers to these questions are not known by all the relevant personnel at the mine, any attempt to implement preconditioning will be very difficult and the likelihood of unsuccessful implementation will be greatly increased.

- **Education and training in the correct application of the technique:** It was also found that proper education and training have great importance for the correct application of the technique. The key issues for the successful implementation of preconditioning are "how to implement the technique correctly" and "why correct implementation is necessary". If these are not addressed properly during the education and training programme, the consequence will be poor application of preconditioning.

- **Resistance to change (i.e. conservative mindsets):** Historically, there is a resistance to new methods and techniques at some levels in the mining industry. The feeling of some mining people is along the lines of "I've been doing this work for many years, why do I need to change now?". It is almost second nature for human beings to develop "tunnel vision" about the way in which a job should be carried out. It is almost impossible to deviate from the routine. This is one of the major hurdles in the implementation of new techniques. This attitude has to be overcome by securing the buy-in from the people who will apply the new technique. This can be achieved by educating, training, discussing success stories, and explaining the benefits of the new technique.

- **Commitment of and follow-up from the mine management:** Continued interest is of paramount importance in the implementation of any new technique. The interest should be emphasised by back-up and follow-up from the mine management. Recognition of successful applications is also a driving force behind the implementation of new techniques.

- **Commitment of the production personnel:** Production personnel must be committed if they are to implement the new technique. This can be achieved if the new technique has the buy-in of the production personnel. A new technique will stay as a "good idea out of many" if it is not "brought to life". The personnel implementing the technique must believe in its benefits to them and must have ownership of the technique and pride in its success.

- **Follow-up by regular audits and feedback by the rock engineering department:** As a first step, the rock engineering personnel must familiarise themselves with the technical aspects of the technique. Once these are mastered, continuous monitoring and regular audits need to be conducted by the trained rock engineering personnel. Assessment of the effectiveness of the technique must be reported back to management and to the personnel who are responsible for the implementation of the technique. Reports should include any significant changes to the working environment (i.e. hangingwall conditions, seismic damage, etc.), identified shortcomings, and recommendations to solve problems.

- **Rock engineering knowledge of production personnel:** Basic fundamentals of rockmass behaviour are generally not well understood by production personnel, who are subjected to severe production pressures. Rock engineering personnel should assist in the training of production personnel on basic concepts and how to recognise the effects of properly implemented preconditioning.

- **Acceptance of research findings:** It is a general perception in the industry that preconditioning works well during the research stage, as dedicated personnel are appointed during this period. It is felt that increased supervision is the reason for the improvement in conditions and not necessarily the preconditioning itself. Although this is true to some degree, some measurement data are available from preconditioning sites indicating that preconditioning causes very significant positive changes in the rockmass behaviour.

- **Recommendations by inexperienced parties:** There is a great danger of getting recommendations from parties not experienced in preconditioning. Incorrectly implemented preconditioning can lead to a worsening of conditions. It is better not to implement the technique than to implement it with inadequate knowledge and experience.

- **Requirement for risk assessment:** It has recently become the norm to conduct risk assessments on every aspect of mining processes. The Department of Minerals and Energy (DME) insists on risk assessment prior to the implementation of preconditioning. This should not be seen as additional work or a burden but rather as a learning opportunity. Owing to the nature of mining, conditions may vary in different mines and in different reef types. During the risk assessment procedure, valid comments can emerge that will improve the technique.

- **Presence (or absence) of a mine champion:** As in every aspect of business, success depends largely on a dedicated champion who will take ownership of a new project. This is also true for preconditioning. If one person at the mine champions preconditioning, the success of the technique is more likely. It is important that this champion should keep in contact with other industry champions and researchers so that he / she can communicate new information related to preconditioning. Absence of a champion will impact negatively: individuals will create an excuse not to pursue the technique and there will be no one to whom problems can be addressed.

- **Changes in production personnel**: The importance of education and training was emphasised above. If some of the production personnel are replaced with new crew the knowledge of preconditioning will be lost. It will take some time for the new crew to adapt to the environment and the technique. This must be addressed by the provision of the necessary training to new members of the team.

- **Availability of right equipment and material:** Owing to the lack of availability of 3.2 m long drill-steels, the majority of past and current preconditioning applications were done with the use of 2.4 m drill-steels, which can effectively drill 2.1 m long holes. Research has shown that the effectiveness of preconditioning was significantly reduced when preconditioning holes were drilled only 2.1 m long instead of the recommended 3.0 m. Efforts must be made to ensure that 3.0 m long preconditioning holes are drilled.

Most of the gold mines have changed their blasting system from igniter cord and fuse to electric or non-electric detonation systems. However, some mines are still using the igniter cord fuse system. In these mines, production holes are normally charged with 1.2 m long fuses, but the preconditioning holes require 2.1 m long fuses. In order to achieve the successful timing of preconditioning, it is recommended that all production holes should be charged with 2.1 m long fuses, too. As these long fuses are not readily available, sometimes all production and preconditioning holes are charged with short fuses. Although this does not generally lead to a misfire, a very ineffective preconditioning blast results as the stemming column of the preconditioning hole is removed by the production blast that takes place around it.

Some production personnel whose duty is the charging up of the blastholes ignore the importance of stemming for blast efficiency. Many preconditioning holes have been blasted with no or very short stemming. The condition of the sockets from the previous day's preconditioning holes is a very good indicator of the effectiveness of preconditioning. The presence of a highly fractured (i.e. crushed) zone around a preconditioning blasthole and difficulty in observing clearly defined sockets are the indicators of a good preconditioning blast. On the other hand, an almost intact preconditioning blasthole socket is an indicator of either poor stemming or incorrect timing of the blast round.

Since the production holes are normally drilled 1.1 m long, 1.5 m long charging sticks are sufficient to load explosive cartridges. In order to properly charge a 3 m long preconditioning hole, 3.5 m long charging sticks are required. Owing to the lack of availability of these long charging sticks in the stope, production personnel use short charging sticks to load explosive cartridges into the preconditioning holes. This results in insufficient charging of preconditioning holes and, therefore, less effective preconditioning.

Low-pressure compressed air supply results in extended time spent on drilling conventional production holes and limited time available to complete the drilling of preconditioning holes in one shift. Under these conditions some drilling teams then give priority to completing the production round without drilling the preconditioning holes. Some drill operators stated that the compressed air pressure is sufficient to drill shorter production holes but not the preconditioning holes. The real problem could be the insufficiency of stope drill machines to operate with longer drill-steels.

- **The perception that preconditioning entails extra work:** After 2.5 years of continuous preconditioning at the project site the implementation of preconditioning was terminated by the workforce following the withdrawal of the project team. It was reported by the rock engineering department of the mine that one of the reasons for the termination was that the workforce claimed that preconditioning was extra work so an additional payment should be made to them in the form of a bonus. However, the mine management was not prepared to pay extra bonuses for preconditioning as the workforce was already paid better bonuses as a consequence of improved productivity (i.e. face advance per blast) that preconditioning had brought about.

It is true that the implementation of preconditioning results in extra work for a drilling crew. But, if the benefits of preconditioning are considered (e.g. a much safer and easier working environment and increased productivity), it can be argued that the workforce will already be gaining some advantages from implementing preconditioning, so no additional payment is necessary. However, since productivity is increased and the cost of mining is reduced with preconditioning, the mine could afford to pay an additional incentive bonus to encourage the continuity of implementation.

- **Production pressure:** Owing to the increased pressure on the production personnel closer to the monthly measurement day, they tend to give lower priority to preconditioning and this results in sub-standard or no preconditioning at all. This normally happens during the early stages of the implementation of preconditioning at a particular slope before it becomes apparent to production personnel that properly executed preconditioning increases productivity (i.e. face advance per blast). In fact, over and above improved safety, the positive effect of preconditioning on productivity is the major benefit apparent to the production personnel and the major motivation for others to apply it.

- **Integration of preconditioning into the mining cycle:** This is seen as a major problem for the implementation of face-parallel preconditioning. During the drilling of the preconditioning hole, which can take two shifts, no production blast in that particular panel is allowed. Face-parallel preconditioning requires a special drill machine and a drill crew as additions to the normal slope complement. On the other hand, many cases have shown that face-perpendicular preconditioning can be successfully integrated into the mining cycle and does not necessitate an increase in the number of slope workers or additional shift hours. The complaints about the integration of face-perpendicular preconditioning into the mining cycle are believed to be caused by other production-related issues and not preconditioning.

- **Sub-standard preconditioning blast parameters:** The effects of blast parameters on the efficiency of preconditioning were reported in section 5.5. Although minimal differences were observed in the effectiveness of preconditioning as a result of varying the hole lengths between 2.4 m and 3.6 m and the hole diameters between 36 mm and 40 mm, it was concluded that preconditioning holes must be drilled 3 m long and 36 mm in diameter (i.e. same length and diameter of production holes). These recommended blast parameters for preconditioning were communicated to the industry by means of published guidelines for proper implementation of preconditioning and during education and training seminars. However, there still seems to be a lack of knowledge and understanding of correct procedures, and confusion about and disregard for the recommended blast parameters for efficient preconditioning.

  The production personnel at one mine misunderstood what the required length of preconditioning holes should be and thought that it must be three times the production hole length. Although it was explained that the required length of preconditioning holes was not dependent on the production hole length, but rather on fracture zone geometry and the mechanism of preconditioning, this misconception remains. The origin of the incorrect information and instructions is of concern.

  Research has shown that the spacing between the preconditioning holes must not be more than 4 m. In the guidelines, it was conservatively recommended that the spacing should be 3 m. There seemed to be no major problem in adhering to this recommendation in almost all of the implementation cases reviewed. The major problem appears to be that some of the preconditioning holes are not drilled on a particular day. Not drilling a preconditioning hole results in a 6 m spacing between two adjacent preconditioning holes. Since this resultant spacing is greater than the maximum allowable spacing (i.e. 4 m), the ground between these two preconditioning holes is not destressed. In fact it can be considered that the levels of stresses acting on this ground are increased as a result of additional stress transfer from the adjacent preconditioning blastholes. The result is a potential man-made faceburst rather than alleviation of the problem. If it is noticed that some of the preconditioning holes are not drilled on a particular day, the drilled preconditioning holes should not be charged and blasted. In this case, no preconditioning will carry a lower risk than sub-standard preconditioning.

The mistakes made during tying-up and timing of preconditioning holes together with production holes have resulted in either misfires or less effective preconditioning blasts. It is recommended that a preconditioning hole be detonated before the detonation of any production hole within 1 m distance from it. Improved training and supervision are required to address this simple and basic issue.

- **Triggering seismic events:** The triggering effect of preconditioning is seen as an undesired side effect. The stress transfer associated with a preconditioning blast can be readily deduced from a study of the spatial migration of microseismicity induced by the blast. The triggering of larger events by production blasting, on the other hand, seems to be a complicated function of the production history of the stope prior to the events. This triggering appears to depend on factors such as the production rate, the sequence of production from one panel to another, and the time-dependent effects that operate in the rockmass between production blasts. However, well-controlled preconditioning blasts do act to redistribute stresses effectively and can also serve to control the timing of the release of stored strain energy from the rockmass. Thus, preconditioning can trigger larger seismic events in a controlled manner and this is regarded as an additional benefit.

In the light of the points discussed above, the project team felt that there was a definite need for thorough education and training in a carefully structured implementation procedure.