

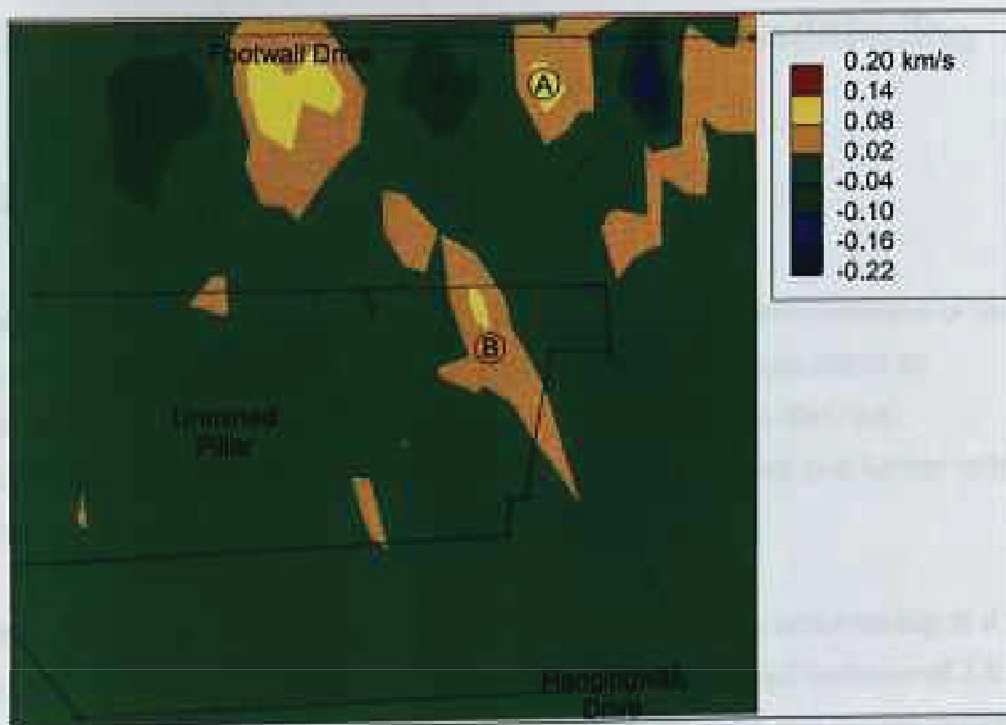


Figure 4.2.21 Straight ray tomographic image of the velocity change following the preconditioning blast (after Maxwell and Young, 1995)

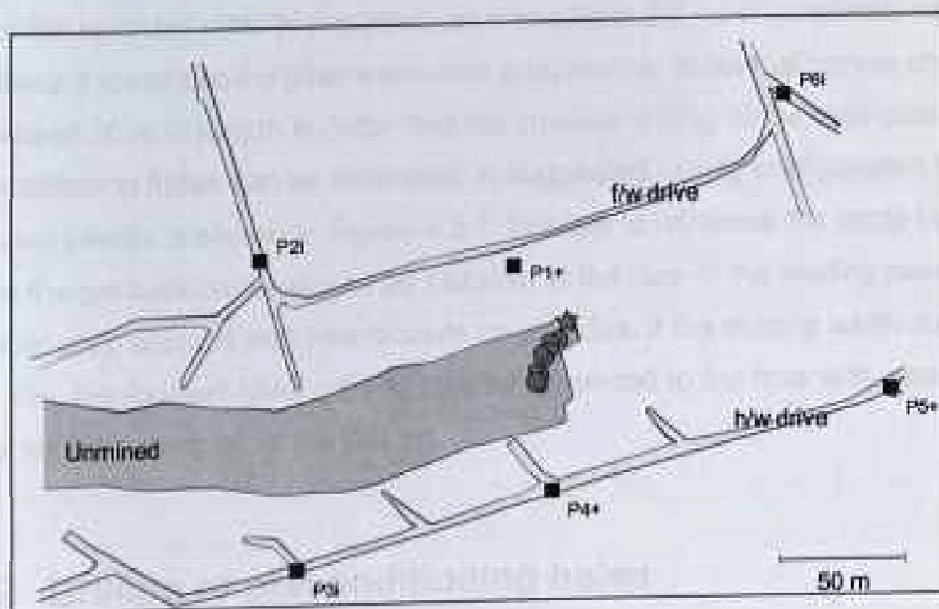


Figure 4.2.22 Plan of the seismicity (filled circles) recorded after the preconditioning blast (filled star)

4.3 Guidelines for face-parallel preconditioning

4.3.1 Introduction

The proposed layouts to maximise the integration and the effectiveness of face-parallel preconditioning into a pillar mining operation were described by *Kullmann, et al. (1995) and Lightfoot, et al. (1995 & 1996)*. Later, the recommended guidelines for this technique were re-compiled and further refined by *Tooper, et al. (1998)*.

The face-parallel preconditioning technique involves drilling and blasting of a ~89 mm diameter hole parallel to a panel at a pre-determined distance of 3.5 m - 5.5 m ahead of it. The technique was designed for an overhand mining layout where up-dip preconditioning holes are drilled from the leading panel below. This experimental technique was carried out on the Carbon Leader Reef. In order to ensure minimal delays to production, a panel lead / lag situation must be in place to accommodate the drilling of the preconditioning holes. The holes are drilled using a dedicated percussion drill rig. Face advance in the direction of the long axis of the remnant pillar is preferred, as it results in the most consistent mining conditions throughout the pillar extraction programme. Individual panels should not exceed 20 m in length in order that the timeous drilling of the face-parallel preconditioning holes can be facilitated. A suggested mining configuration for overhand panels is shown in Figure 4.3.1. In order to minimise the leads between panels the percussion rig should be installed at the face of the leading panel with hydraulic prop support with headboards on all sides. If the stoping width does not allow this, the footwall-lifted gully should be advanced to the face with a possible cubby for the setting up of the drill rig.

4.3.2 Drilling of preconditioning holes

The hole should be drilled parallel to the reef plane along the reef/footwall contact in the fracture zone that naturally develops ahead of the advancing face, and should extend into the rockmass ahead of the panel above as shown in Figure

4.3.1. In this figure, Panel 2 has been mined to limit (the position of the previous preconditioning hole) and the next hole is drilled up to 5.5 m from the current face. The hole must be kept parallel to the face to ensure a consistent preconditioning effect along the entire length of the face. Each hole should be inspected after completion of drilling to verify the hole direction. Severe deviations can cause inconsistent blast results.

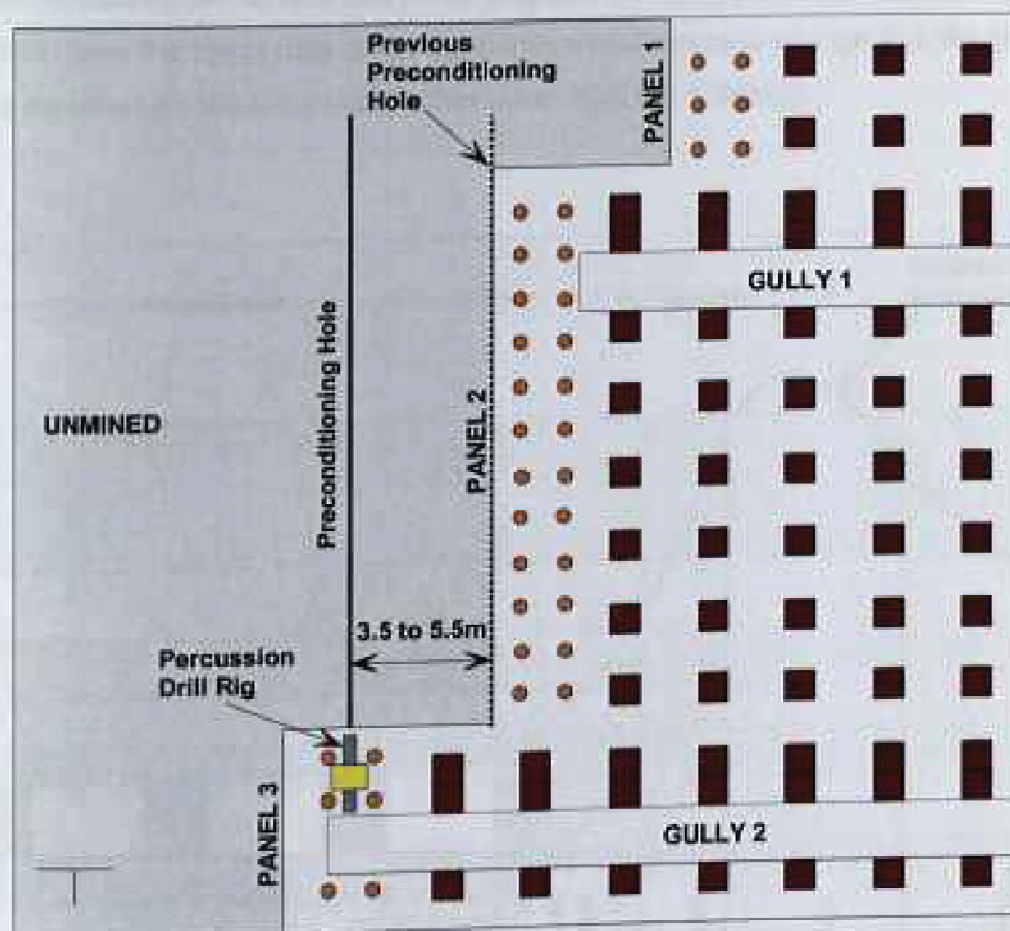


Figure 4.3.1 Face-parallel preconditioning layout in an overhand mining sequence (not to scale)

It is important to ensure that the hole is not drilled beyond the stress peak that exists ahead of the face. It is likely that difficulty will be experienced in keeping the hole open when it is drilled too far ahead of the face. The actual hole positioning will be site-specific and will depend on both the state of stress ahead of the face and the size of charge being used. Experience has shown that blasts from 89 mm-diameter preconditioning holes have been effective when the holes are collared 3.5 m to 5.5 m ahead of the stope face.

Figure 4.3.2 illustrates the resultant effects if the preconditioning hole is drilled from various positions. Blasting too close to the face will result in a minimal preconditioning effect and will cause severe damage to the face area. Beyond the optimum zone there is an area where a preconditioning blast can redistribute stress back towards the face, resulting in stress conditions that could lead to a faceburst. Seismic evidence and numerical modelling results have shown that such re-loading of the face can occur (Lightfoot, *et al.*, 1994, Kullmann, *et al.*, 1994). Near the intact rock zone, the confinement stress is so high that the blast has no effect on the rockmass further away from the blasthole.

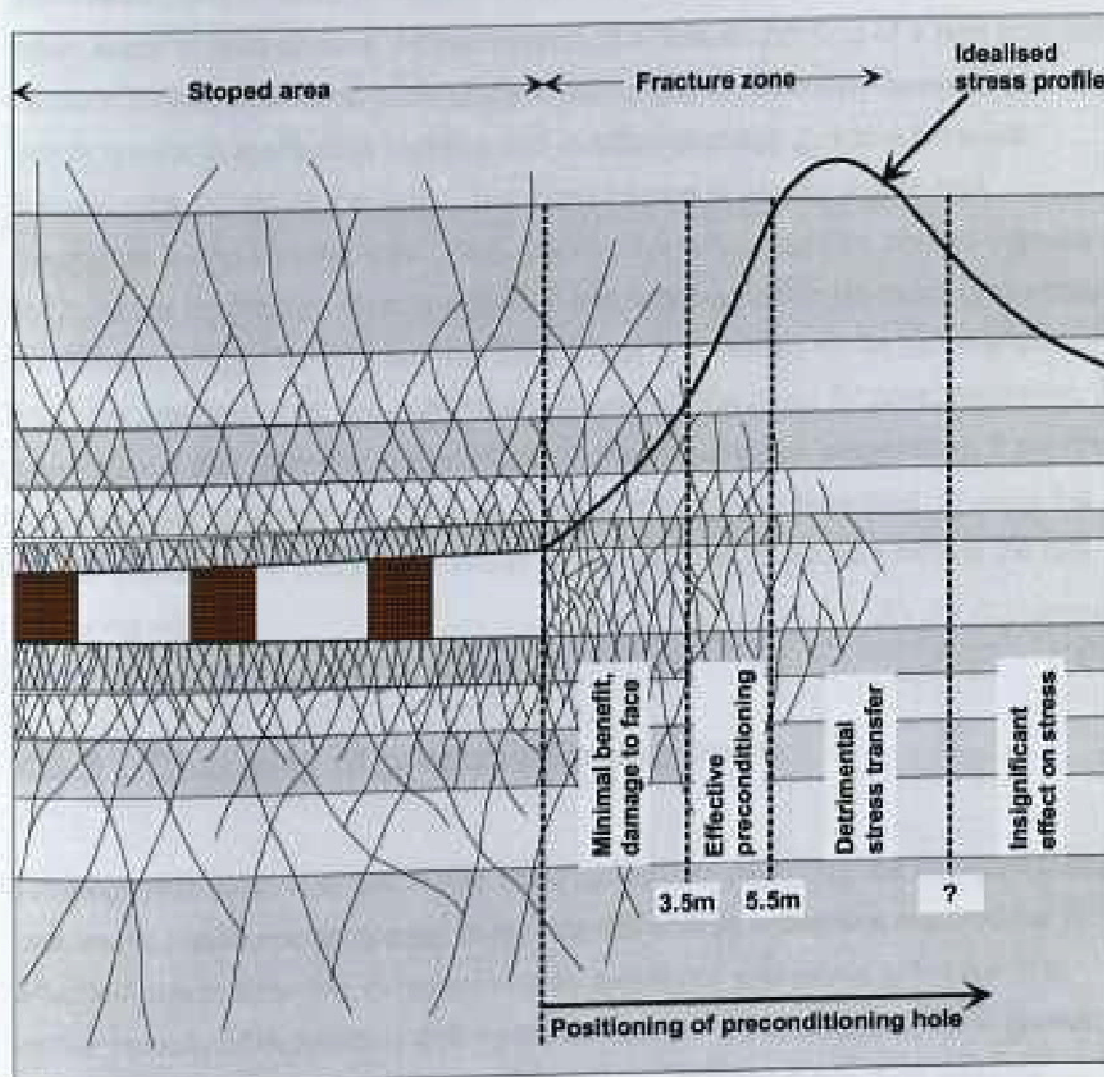


Figure 4.3.2 Effects of positioning a large (~89 mm diameter) preconditioning hole at varying distances ahead of the stope face

As the preconditioning process involves stress transfer from one portion of the rockmass to adjacent regions, a systematic sequence of preconditioning is important. The best results to date have been achieved when the sequence begins with the lagging panel in the stope, and progresses down-dip towards the leading panel. Out-of-sequence preconditioning should be avoided, as it can result in increased stress concentrations on adjacent panel faces.

The time required to drill, charge and blast a preconditioning hole should never exceed two days and the process should ideally be completed in a single shift. Sufficient air pressure and volume are required to ensure a good drilling-penetration rate. Failure to complete the preconditioning process within two days often leads to hole closure. Abandonment of a hole and drilling of a new hole will result in further problems, particularly in terms of the interaction between holes, which results in ineffective blasting and in-stope damage due to a blow-out between the collars of the holes. The loss of holes is usually due to rock fragments falling into the hole. Thus, ideally, the hole should be pressure-grouted for its entire length and then re-drilled. If this is not possible, as much of the hole as possible should be grouted and then a new hole drilled, as far as possible from the previous hole, but within the accepted range given for preconditioning. A hole of a smaller diameter drilled closer to the face may be satisfactory, if the first hole has been abandoned. The use of retract bits is recommended, to avoid the loss of drill-steels in a hole as a result of the collapse of the hole behind the drill-bit during drilling.

4.3.3 Charging of preconditioning holes

Although little experimentation has been carried out regarding the charge density, pneumatic loading does appear to provide the charge properties required for effective preconditioning. A higher loaded density of explosives will result in a higher velocity of detonation and a greater volume of gas and, therefore, greater in-hole gas pressures. This could be desirable, provided there is no adverse effect on the stope face. Normal pneumatic loading of a 89 mm-diameter hole and 15 m charge length would require about 100 kg of ANFO or 120 kg of emulsion explosive.

The detonation of preconditioning holes should be by top-priming the charge to facilitate removal of primers from misfired preconditioning holes. An emulsion cartridge is recommended as a primer and should be initiated with a Nonel or electric detonator. Two detonating fuses may be used as a safety precaution: if the first fuse fails to initiate, the second fuse would be detonated. The primer should be placed about 6 m into the hole, with an additional metre of explosive before the hole is stemmed. The preconditioning hole should be detonated manually, using either an entirely electrical detonation system or an electrical fuse used in conjunction with a secondary Nonel fuse.

4.3.4 Stemming

Several systems of stemming have been evaluated and the most favourable results have been obtained with a combination of crushed rock and clay. The crushed rock should have a particle size of between 1/30 and 1/15 of the hole diameter and should be grit rather than sand, as the angularity of the particles adds to the stemming-retention characteristics. Cartridges of clay and crushed rock can be pneumatically loaded using a capsule gun.

It is recommended that a minimum 5 m of the hole should be stemmed in order to avoid a blowout from the collar of the hole. Best results have been achieved when 1 m of clay adjacent to the explosive column is followed by 4 m of crushed rock. When crushed rock has not been available, five metres of only clay stemming have been used. This type of stemming has produced mixed results including blow-outs and the resulting damage to stope support.

The required length of stemming will depend upon several factors but, from observations made in situations where the stemming did fail, it appears that the most vital factor relates to the depth of fracturing the collar of the hole. To a lesser extent other factors would include the ability of the gas to penetrate the fractured rockmass, the diameter of the hole and the detonation pressure within the blasthole. Although the length of stemming must be kept to a minimum, as this will maximise the charge length ahead of the face for more uniform preconditioning, the hole is required to be stemmed from the collar for a distance

of at least 5 m in order to contain the explosion within the hole. However, the length of stemming required results in the transfer of stress onto this stemmed portion of the panel as discussed by Lightfoot *et al.* (1996).

It was initially thought that the stemming length could be reduced by grouting a short length of the hole near the collar or by using some form of in-hole plugging device (Tooper *et al.*, 1998). Apart from possible difficulties involved in clearing out such material in the event of a misfire, it became evident from tests conducted at the preconditioning site that shortening the stemmed length was not desirable. Conservatively, the hole should be stemmed from the collar for a distance at least equal to the depth of the zone of fracture that is orientated perpendicular to the axis of the hole.

Some alternative means were devised to alleviate the stress loading that has been found to occur in the vicinity of the stemmed portion of the hole. A possible solution to the problem could be to design the preconditioning blast so as to eliminate the need for tamping material. If the hole was bottom-primed, the explosive between the collar of the hole and the advancing explosion front would act as stemming for the blast. The presence of a primer at the back of the preconditioning hole would clearly not be desirable as this increases the probability of a cut-off before the initiation of the blast. Therefore, the detonator should, in fact, be placed as close to the collar of the hole as possible, so as to facilitate recovery of the detonator after a misfire and the initiation sequence of the additional hole(s) relative to the main preconditioning blast.

An alternative could be to drill additional shorter holes of smaller diameter between the main hole and the panel face to precondition the area not suitably affected by the main preconditioning blast. Figure 4.3.3 (a) illustrates this concept for an extra hole drilled parallel to the main hole. Such an arrangement would need to be carefully designed to take into account the influence of each blast on the other hole and to allow for the treatment of possible misfires.

A layout that would probably be more amenable to practical application is shown in Figure 4.3.3 (b). The idea would be to set off the main face-parallel preconditioning blast as usual. Additional face-perpendicular preconditioning

blasts could then be set off, just after the main blast or with the normal production blast, in the stemmed area, to counter any possible undesirable stress transfer resulting from the main preconditioning blast.

4.3.5 Dealing with misfires

Multiple detonators should be used to minimise the risk of misfires. Both removable stemming and top-primed holes would facilitate the removal of the primers should a misfire occur. It is further recommended that explosives of minimal impact sensitivity be used for the preconditioning. By doing this, in the event of a misfire or of a cut-off of the explosive in the hole, production drilling into the hole would not set off the explosive that had not detonated during the preconditioning blast.

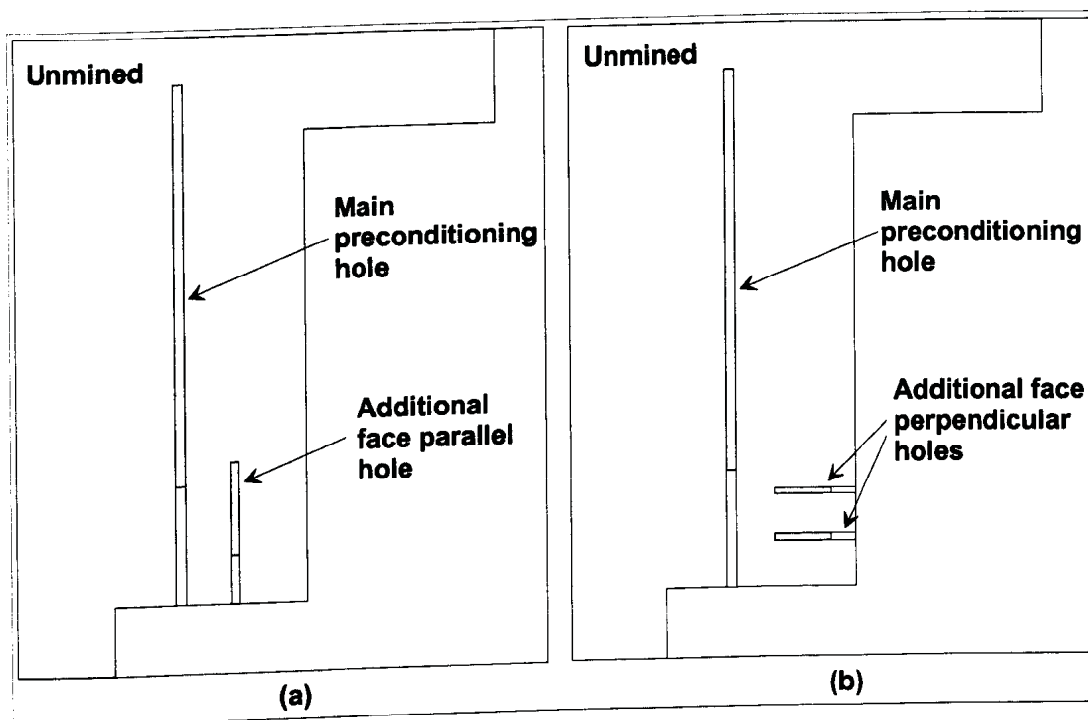


Figure 4.3.3 (a) Use of second hole, parallel to main hole, to precondition stemmed area. (b) Use of additional holes, perpendicular to panel face, to precondition stemmed area

4.3.6 Assessing the effectiveness of preconditioning blasts

An effective blast should reveal a “bulking” of the face, with minor amounts of scaling from the face. Minor “shake-out” of loose rock from the hangingwall is likely to occur, even if the area has been barred and made safe. Footwall heave indicates that the hole has deviated in the footwall towards the face and too much blast energy has been lost through the footwall, rather than being used to dissipate energy from ahead of the face.

The seismic efficiency of a blast defined by seismic energy released expressed as a percentage of explosive energy is typically less than one percent. A blast consisting of 100 kg of ANFO should generate a seismic event in the order of $M = 1.0$ (from the formula $M = (\text{Mass of explosive (kg)} / 100) \pm 0.5$). A well-executed preconditioning blast will typically result in a seismic event of $0.5 \leq M \leq 1.0$. If an event of larger magnitude is generated, then a simultaneous release of stored strain energy has occurred with the blast. If the blast triggers a large event, this is usually the result of the stress transfer that accompanies a successful preconditioning blast. This stress transfer is seen as a migration of microseismic events further ahead of the face and into other portions of the pillar.

Convergence measured on the day after the blast should generally be in excess of 15 mm within 2 m of the face of the preconditioned panel. Other panels in the vicinity of the blast will also usually show an increased convergence rate for the period of the blast.

4.3.7 Blast optimisation

The optimum blast configuration will vary from one slope to another, but the general principles will not change. A compromise must be attained between blast size and the time required to achieve this blast. The bigger the blast, the more effective it can be in preconditioning the rockmass ahead of the face. It also allows for the hole to be positioned farther ahead of the face and thereby

precondition more ground with one blast, resulting in a more efficient cycle. The drawback is in the increased time required to drill a larger hole and the difficulties of drilling in a more highly stressed environment. The beneficial effects of preconditioning appear to be transient in nature, so that the longer the time period between preconditioning blasts, the more strain energy may again accumulate ahead of the face. This seems to apply even if the face is not mined for a while.

The efficiency of any explosive is affected by charge diameter. For an ANFO-type explosive, the maximum efficiency is achieved with holes in excess of 150 mm in diameter. Emulsion explosives have a better performance in smaller holes than does ANFO. However, the two explosive types have not shown any difference in terms of the results of preconditioning blasts, probably because the variability in the rockmass from one blast to another overshadows the difference in explosives.

There is an improved efficiency in the behaviour of the stemming within holes of smaller diameter. Therefore, less stemming may be required in smaller holes than in larger ones, so that a greater proportion of face length can be "covered" by the charge length, and more uniform preconditioning can result.

4.4 Summary

Face-parallel preconditioning is a very effective method of preconditioning as can be seen in the very pronounced strain energy release and stress transfer evident from the seismic data, and the significant convergence recorded after face-parallel preconditioning blasts. However, its implementation can be very difficult under many circumstances, owing to the practical limitations of this method. The need for special drilling equipment, a separate drill crew and access ahead of the panel to drill the holes all complicate the application of face-parallel preconditioning. In special cases, however, this method of preconditioning may be the only way of safely extracting highly stressed ground, and it appears to be an effective method for pillar extraction.

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 of actually modifying the material properties of the rock, the zone that is preconditioned is still capable of carrying high loads. After a 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.

Of practical significance is that stress transfer is a dynamic, ongoing process. The stress is redistributed in the rockmass in response to both mining and preconditioning. 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.

Clearly in the case studies referred to, well-controlled preconditioning blasts redistributed stresses effectively and also served to control the timing of the release of stored strain energy from the rockmass. Poorly controlled preconditioning blasts, on the other hand, either did not redistribute stress effectively or acted to induce unfavourable stress redistribution (i.e. the movement of stress towards the face rather than away from it).

5 FACE-PERPENDICULAR PRECONDITIONING

5.1 Introduction

The face-parallel preconditioning method produced very successful results and appeared to be well suited to the mining of long and narrow strike pillars. However, it would be difficult to implement this method in a normal deep-level longwall production environment without the creation of considerable delays in the mining cycle. For this reason, in late 1994, a new experimental site was established on a deep-level longwall stope, the 87-49W at Mponeng gold mine (ex-Western Deep Levels South gold mine). This site had been experiencing a serious facebursting problem. Here, a different preconditioning technique was tested, which involved drilling and blasting short face-perpendicular preconditioning holes as an integral part of the actual mining cycle.

5.2 Test site

The 87-49W stope is located at the south-west corner of Mponeng gold mine, about 2500 m below surface. The mining of this stope is on the Ventersdorp Contact Reef (VCR), with an Albion formation (i.e. hard) lava hangingwall and Wit's quartzite footwall. The reef dips at an average of 22° to the south with a channel width between 1.2 m and 3 m. The hangingwall and reef are characterised by rolls and jointing.

Initially, mining took place in the strike direction towards the west. However, the dominant joint set was orientated in the dip direction parallel to stope faces, which caused serious face bursting and associated instability problems in the face area. For this reason, it was decided to change from breast mining to an up-dip mining geometry at the end of 1992. The levels of damaging seismicity were reduced by this change in the mining direction but facebursts were still experienced. Thus, at

the end of 1993, the Rockburst Control Project Team of CSIR / Miningtek was asked to undertake a preconditioning project in this stope.

The face-perpendicular preconditioning began on 23 May 1995 on a single up-dip panel, the West 3. During the course of 1995, preconditioning was initiated on other adjacent panels. The face-perpendicular preconditioning minimised faceburst incidences and a significant improvement in hangingwall conditions was noted. Consequently, the rock-related in-stope accident rates declined significantly.

However, in August 1995, the mining direction was again changed, from up-dip to diagonal mining, which is a compromise between breast and up-dip mining. The decision was taken to increase the available face length in order to increase production. The rock mechanics aspects of this change in mining direction were not thoroughly considered. Shortly after the introduction of diagonal mining, the hangingwall conditions started to deteriorate and serious instability problems were experienced. Several rockbursts occurred, as irregularly shaped pillars were formed when the diagonal panels were mined out along the stability pillar at the top of the stope. An example is the rockburst that resulted from a $M=1.9$ seismic event on 15 February 1996, which caused five injuries and damage to the West 2 diagonal panel. A rockburst investigation team from CSIR / Miningtek visited the site with the objective of determining the cause of the rockburst in order to prevent future occurrences. A detailed description of this investigation is given in Section 5.3.2.

Subsequently, mine management decided to change the mining direction back to the up-dip geometry. After a period of re-establishing the mining faces the stoping has continued with up-dip panels again. Since reverting back to up-dip mining geometry, the ground conditions have improved significantly. The regular mining configuration lent itself much more readily to the assessment of the effectiveness of preconditioning and an optimisation study was undertaken. Figure 5.2.1 shows different phases (i.e. mining directions) of the project term.

The completion of the optimisation study at the 87-49W stope in February 1997 marked the end of the field work associated with the preconditioning experiment at the site.

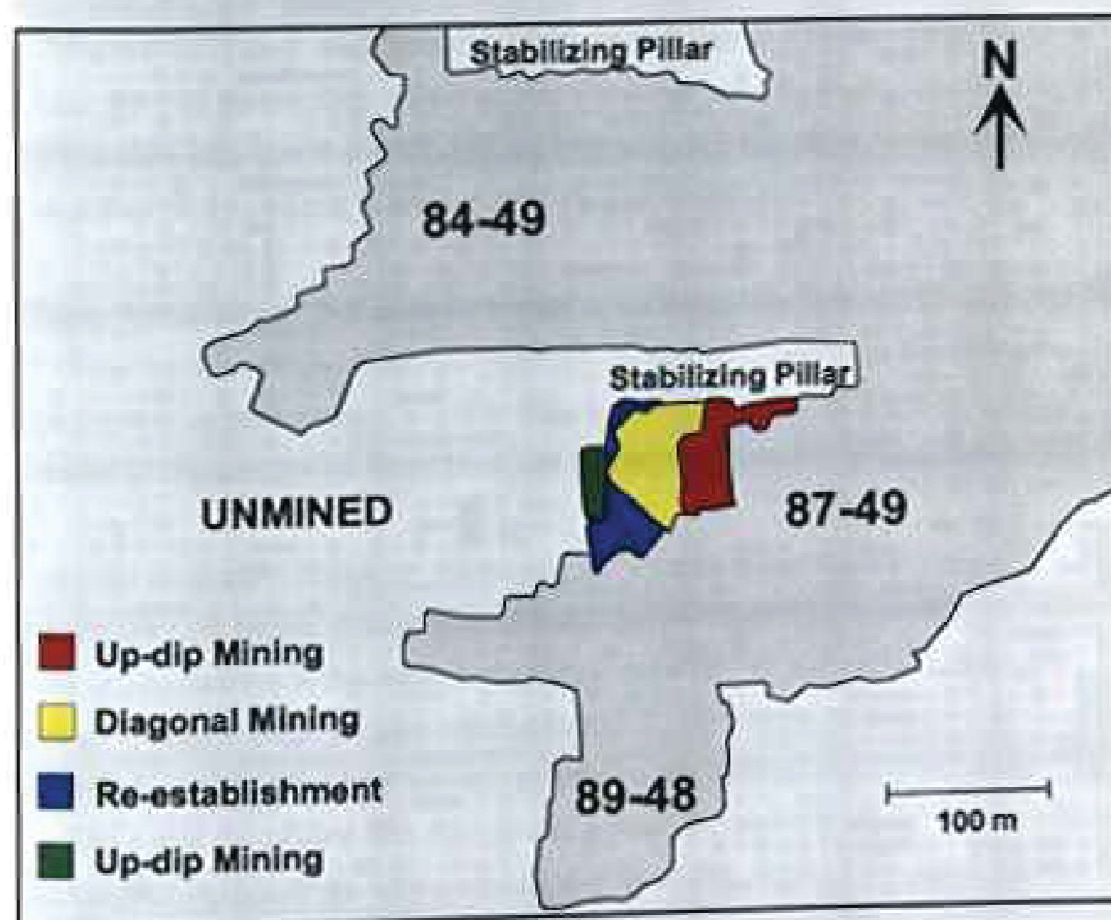


Figure 5.2.1 Test site (87-49W stope), showing different phases of mining

5.2.1 Preconditioning layout

A review of the previous face-perpendicular preconditioning layouts was undertaken. This included an assessment of the early work by Roux *et al.* (1957) at ERPM and Giltner's (1992) proposal for an alternative method to the preconditioning being implemented by COMRO at that time.

The ERPM experiment used short (i.e. 3 m), small diameter (i.e. ~36 mm) blastholes and was applied in more than 30 stopes. Hill and Plewman (1957)

concluded that, compared with conditions elsewhere on the mine, the hangingwall and face conditions were markedly improved. It was further concluded that the incidence of rockbursting was reduced.

Giltner's (1992) work also followed the ERPM model and utilised small diameter holes, 38 – 42 mm, drilled 2.25 m apart. The main difference with respect to the ERPM trials was that the preconditioning holes were suggested to be drilled and detonated as an integral component of the production blast.

Giltner had assumed that each individual preconditioning hole would have a zone of influence of a radius of approximately 0.75 metres. In order to test Giltner's assumption experimentally, two 3 m face-perpendicular holes were drilled and blasted at Blyvooruitzicht Gold Mine preconditioning site on 14 December 1993.

Ground Penetration Radar profiles were acquired before and after the preconditioning blasts. The effects of the experimental blasts were clearly visible as a strong change in the reflection pattern observed on the radar images and shown in Figure 5.2.2. A clear intensification of pre-existing fractures was observed on post-blast profiles. By comparing the "before" and "after" blast profiles it was concluded that the zone of influence around the face-perpendicular preconditioning blasthole was around 1.5 m in radius, double that assumed by Giltner (1992).

The drilling procedure for the preconditioning holes allowed for the use of drilling machines and drill-steels already available on most mines. This obviated the need for the purchasing of special equipment. The preconditioning holes were drilled by hand-held percussion drill machines with air-legs.

In order to achieve the maximum effect from the blast, the preconditioning holes were drilled on the reef plane. As the radial extent affected by the preconditioning hole was determined to be 1.5 metres, the spacing between preconditioning holes along the face did not exceed 3 metres, as shown in Figure 5.2.3. Support close to the face creates the problem of limited space for drilling long holes in the face area. For this reason, all preconditioning holes were drilled in the spacing between the dip lines of packs.

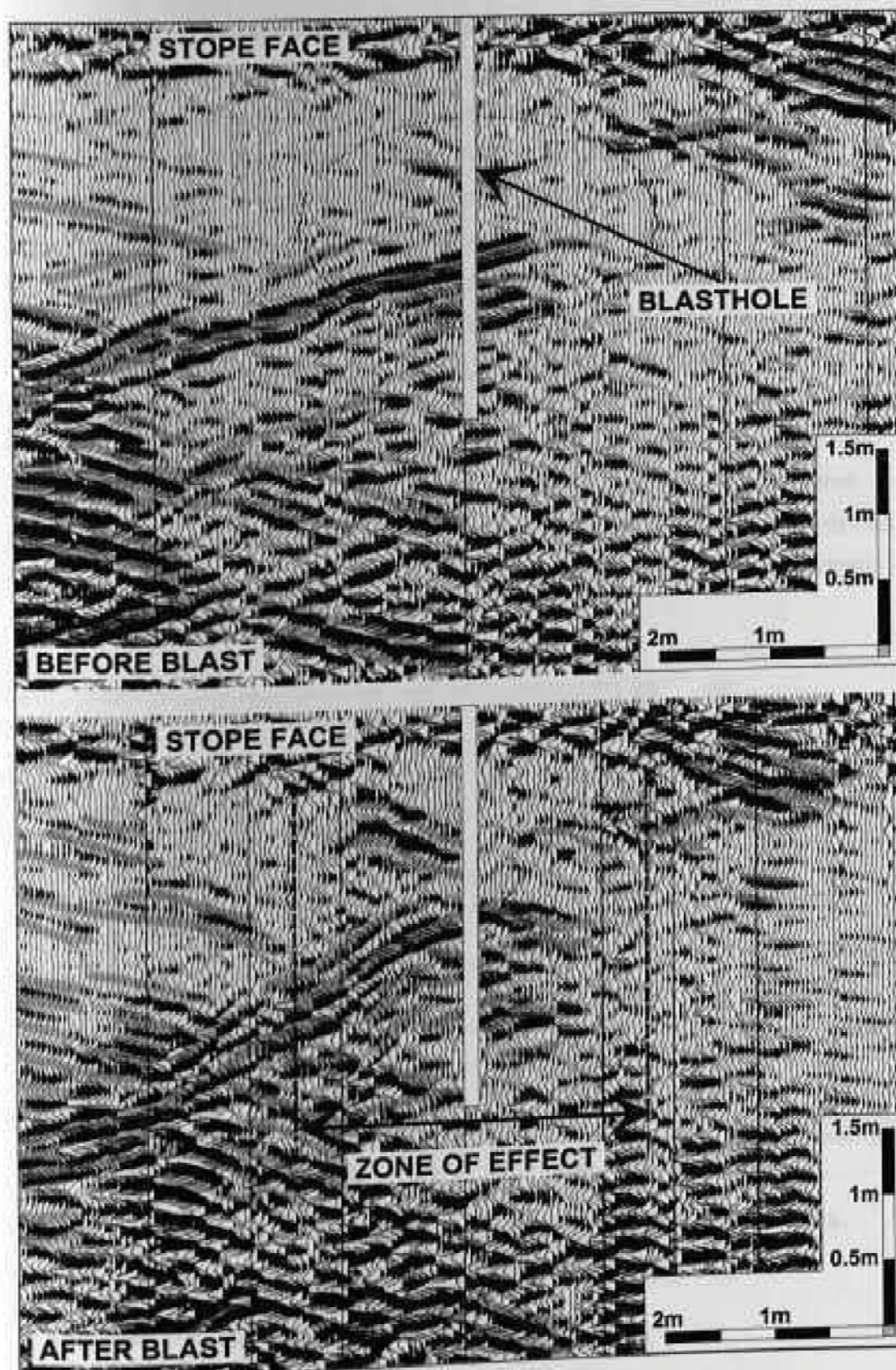


Figure 5.2.2 Ground Penetrating Radar scans before and after the test blast

The mining cycle in the panels was a three-day cycle, as shown in Figure 5.2.3. This figure represents a plan view of an up-dip panel. On day one the 3 m-long preconditioning holes shown with light grey lines were drilled perpendicular to the face and spaced at 3 m. These holes were charged and detonated together with production holes. Once the face had been cleaned and prepared for the next round of production, the drilling of new preconditioning holes commenced. Each new round of preconditioning holes was offset from the previous ones by about 50 cm along the face in order to avoid drilling in the position of existing sockets. So, on the second day the preconditioning holes shown with darker grey lines and similarly, on the third day, the preconditioning holes shown with black lines were drilled and blasted with production holes. In this way the preconditioning holes drilled on the first day of a new three-day cycle were drilled in the same position as those on the first day of the previous cycle as the face was advanced minimum 3 m with three production blasts so there were no longer any sockets remaining in these positions.

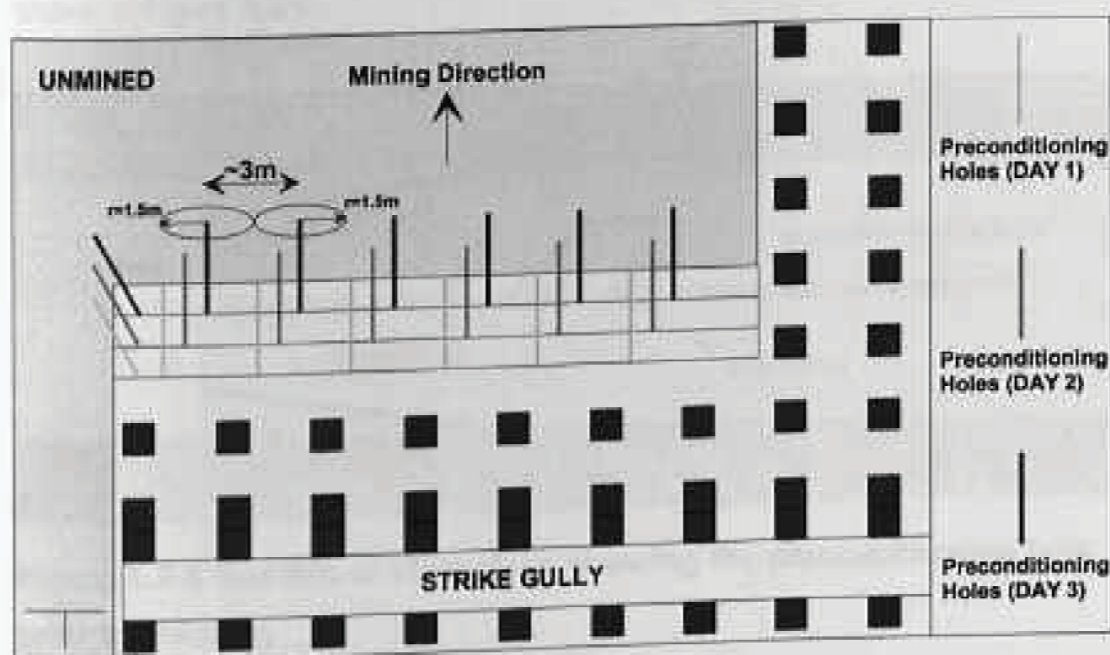


Figure 5.2.3 Layout of face-perpendicular preconditioning holes, showing radius of influence of each hole ($r = 1.5\text{ m}$) and the recommended spacing between holes (i.e. 3 m)

The preconditioning holes were drilled at right angles to the face at mid-stope height in order to reduce the chance of a hole drilled as part of the normal

production round intersecting a preconditioning hole. The closest point between the production and the preconditioning holes was at the collar and, when properly drilled, the production holes were drilled away from the preconditioning holes as shown in Figure 5.2.4. "Knock-off" button bits were used to drill the preconditioning holes as this eliminated the need to take long drill-steels out of the stope for re-sharpening at the end of the shift.

The rock in the stope face was fractured and some of these fractures were tightly closed. Thus, low shock-energy and high gas-energy explosives were required in order to open and extend pre-existing fractures. ANFO-type (ammonium nitrate fuel oil mixes) explosives were recommended for preconditioning but were not available at the project site. Powergel emulsion cartridges were the only type of explosive available and were used at the site. Only 2/3 (i.e. 2 m) of the total hole length was charged with 15 Powergel cartridges (i.e. a total mass of approximately 2 kg) and the remaining 1 m was tamped with clay cartridges as shown in Figure 5.2.4.

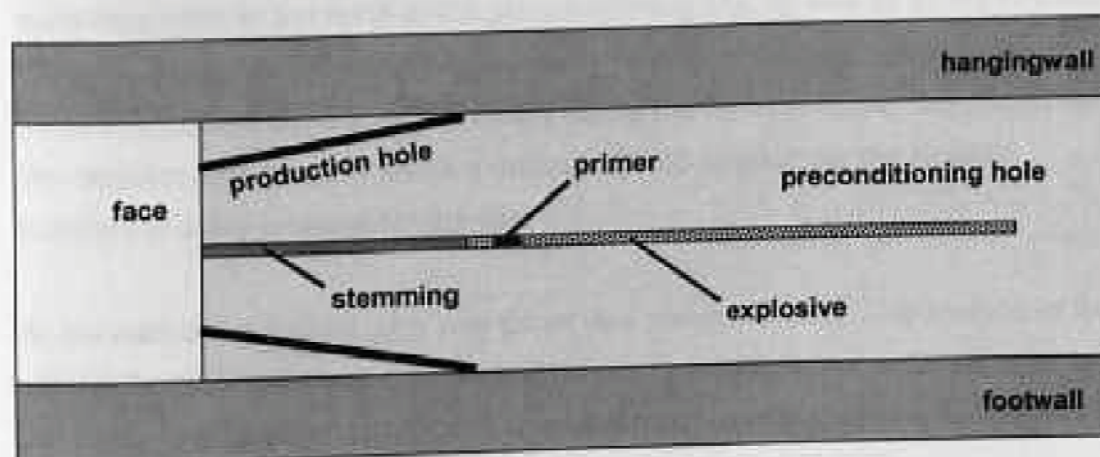


Figure 5.2.4 Section of stope face showing the preconditioning hole prior to blasting

The charging of preconditioning holes was done by top priming the explosive charge to facilitate easier removal of primers from misfired preconditioning holes. One emulsion cartridge was used as a primer and initiated with a Nonel detonator. Although the application of fuse and igniter cord systems was not recommended because of the difficulty of obtaining the proper firing sequence of preconditioning holes in relation to the production holes, a reliable and accurate

electronic initiation system was initially not available at that particular stope. The existing initiation system, which was an ordinary fuse and igniter cord system, had to be employed. To ensure the proper firing sequence, all preconditioning and production holes were charged by 2.1 m long fuses and the fuses of the preconditioning holes were connected to the igniter cord approximately 1 m forward as shown in Figure 5.2.5. This enabled the preconditioning holes to be fired with almost a 1 m burden before the neighbouring production holes were fired.

5.2.2 Instrumentation and monitoring programme

Seismic coverage

Seismic coverage of the site was provided by a Portable Seismic System (PSS) microseismic network, which monitored seismicity associated with the 84-49 stabilising pillar to the north of the preconditioning site, as well as by the regional Integrated Seismic Systems (ISS) network. Neither of these systems was able to provide adequate coverage for the new site at the 87-49W stope. Consequently, the decision was made to install a dedicated PSS network for the seismic monitoring of the preconditioning site.

At the start of the project, only one panel was preconditioned. The analysis of the seismicity associated with the preconditioning required data of sufficient sensitivity and location accuracy to distinguish between the seismicity from the preconditioned panel and that from adjacent panels.

The positions of the 84-49W stability pillar and the 87-49W stope are shown in plan in Figure 5.2.6. The layout of the PSS network is shown in plan in Figure 5.2.7. The positioning of the five triaxial geophone sensors labelled 'OS1' to 'OS5' in Figure 5.2.7 was a compromise between the desired coverage of the preconditioning site and the constraints imposed by the existing development around the 87-49W stope. The major constraint was the lack of access to the south and west of the mining. The resulting network had dimensions of 350 m in

the strike direction, 200 m in the dip direction and 85 m in the vertical direction, roughly centred about the mining faces of interest.

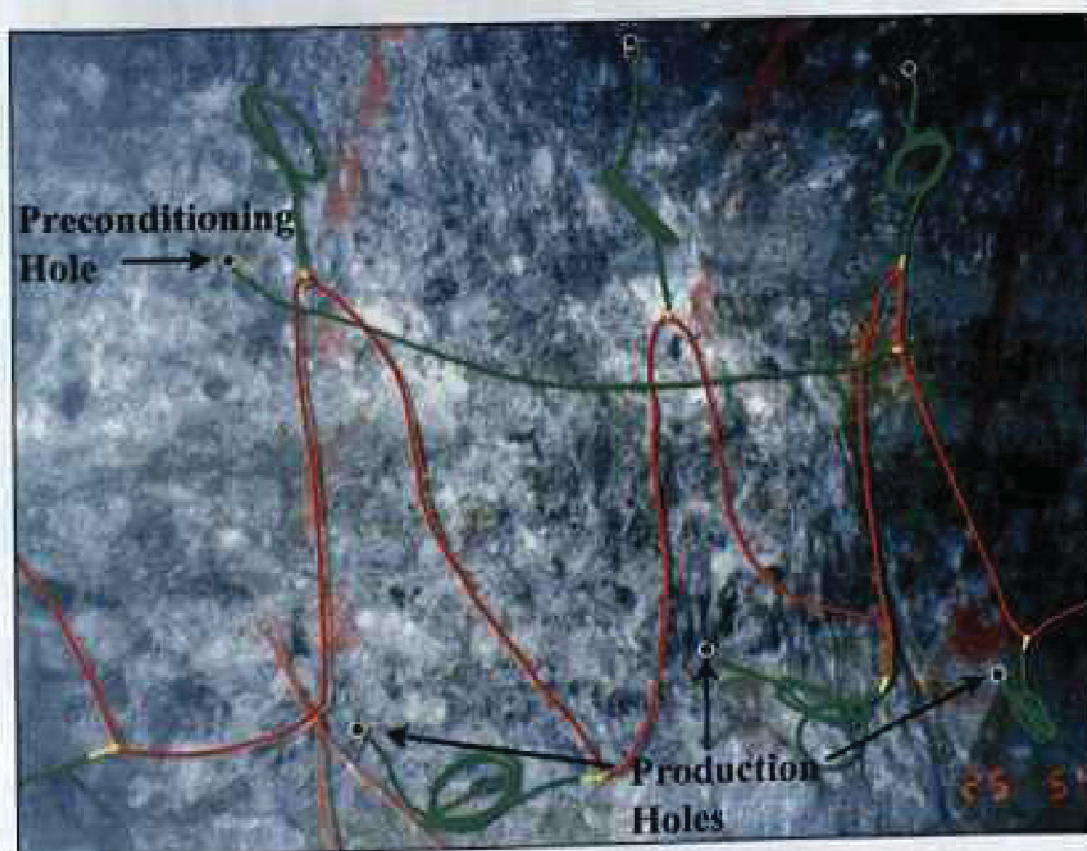


Figure 5.2.5 Preconditioning as an integral part of ordinary fuse and igniter cord tie-up system

The sensors at 'OS1i' were installed at the end of a 10 m down-hole drilled into the footwall quartzites from 84 level footwall-access crosscut. The sensors at 'OS2i' were installed at the end of a 15 m horizontal hole drilled into the hangingwall lavas from 84 level reef drive. The sensors at 'OS3i' were installed at the end of a 30 m up-hole drilled into the hangingwall lavas from 87 level reef drive. The sensors at 'OS4i' were installed at the end of a 10 m up-hole drilled into the footwall quartzites from a follow-behind development on 87 level. The sensors at 'OS5i' were installed at the end of a 10 m up-hole drilled into the lavas from an 84 level crosscut.

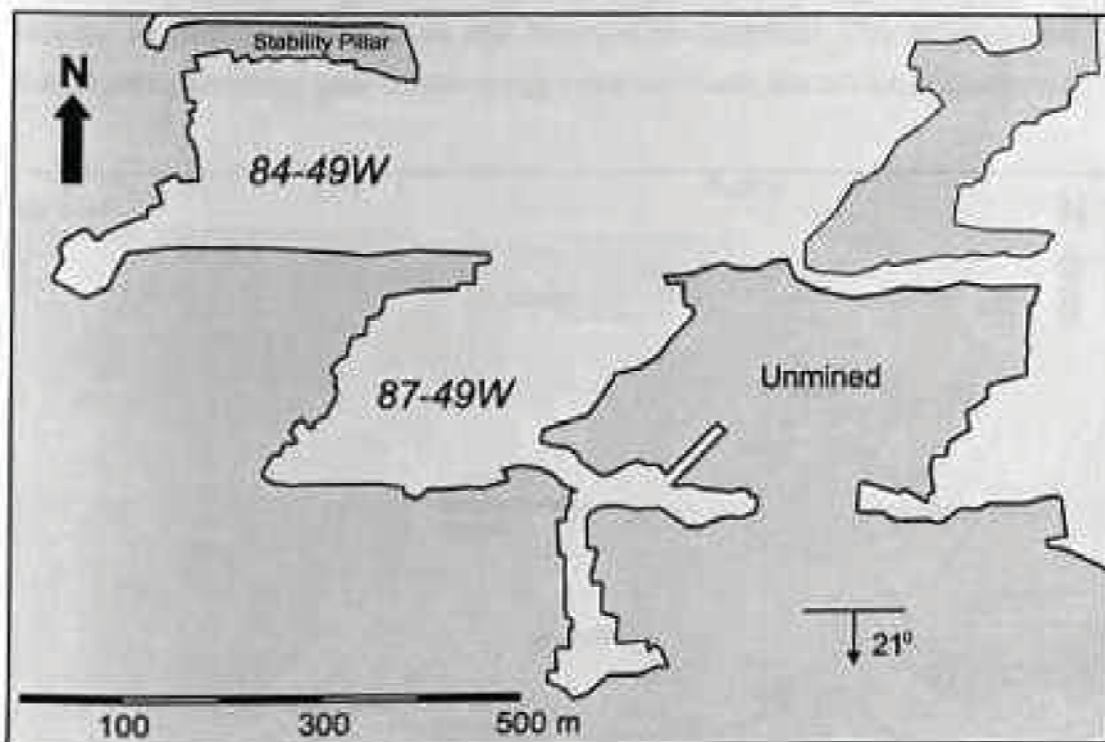


Figure 5.2.6 Plan of a portion of the Mponeng gold mine, showing the positions of the 84-49W stability pillar and of the 87-49W stope, which is the preconditioning experiment site

The Data Acquisition Unit (DAU) was housed in an enclosure behind the waiting place near 'OS5i' on 84 level. The cables carrying the signals from the five triaxial geophone sensors were brought together at the DAU, where the data was digitised and passed through to a computer (PC) on surface.

In 1996, several improvements were made to the PSS network. These included the replacement of substantial lengths of underground cabling, which had been repeatedly vandalised or damaged by mining machinery, between the DAU and the geophone outstations near the recording sites.

The mining of the 87-49W longwall resulted in the area of active mining moving away from the focus of the seismic network. In an effort to counteract this, two of the recording sites were relocated, namely 'OS2' and 'OS5', and this relocation is shown in Figure 5.2.8. A third site 'OS3' was also relocated, partly to improve its position, but also to improve the signal quality at the site. Consequently, the

location accuracy was adequate with this new configuration. This improvement in the location accuracy was confirmed by calibration with known blast locations.

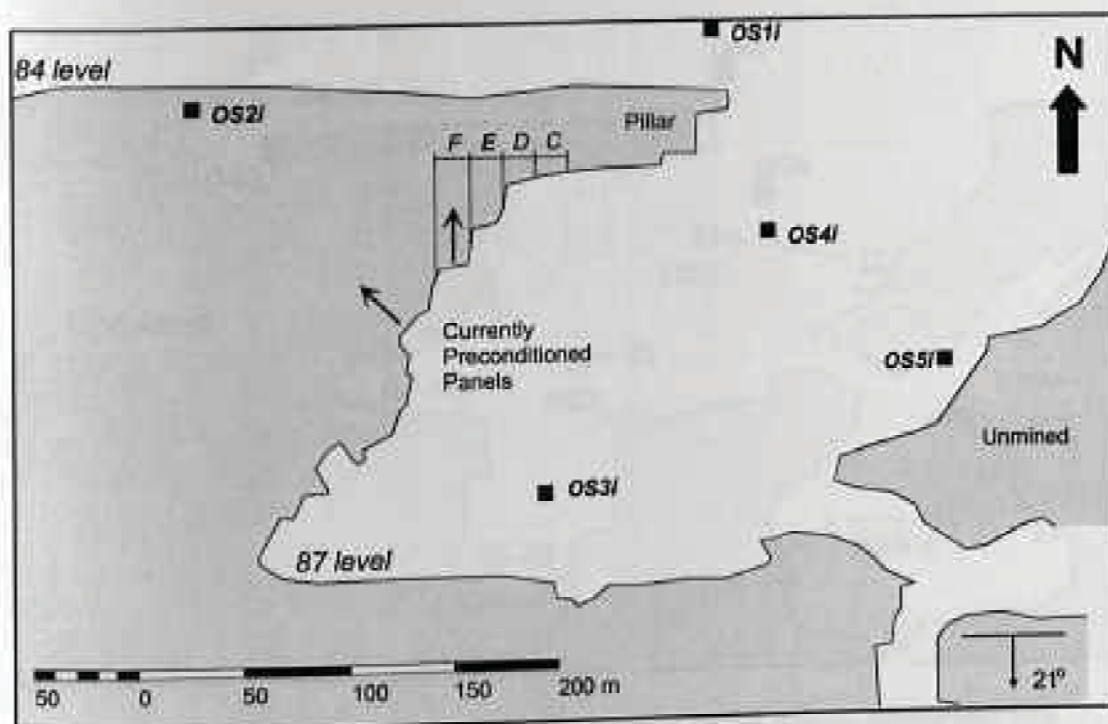


Figure 5.2.7 Plan of the preconditioning site, showing the layout of the PSS network monitoring the experiment. The triaxial geophone positions are indicated by squares labelled 'OS1/' to 'OS5/'

Convergence Measurements

Deformation of the rockmass ahead of a stope face occurs in response to factors such as seismicity, face advance, preconditioning and time-dependent effects. The changes experienced in the rockmass can be reflected in the convergence record within the stope.

In order to capture any change in the rockmass response due to the preconditioning, 51 convergence stations were installed and measurements taken at the project site during the monitoring programme. These are termed "long period" measurements, as they are obtained by taking daily convergence readings with typically a 24-hour interval between successive data points (Piper

and Grtunca, 1987). Figure 5.2.9 shows the relative positions of all measuring stations, which are numbered according to the installation sequence.

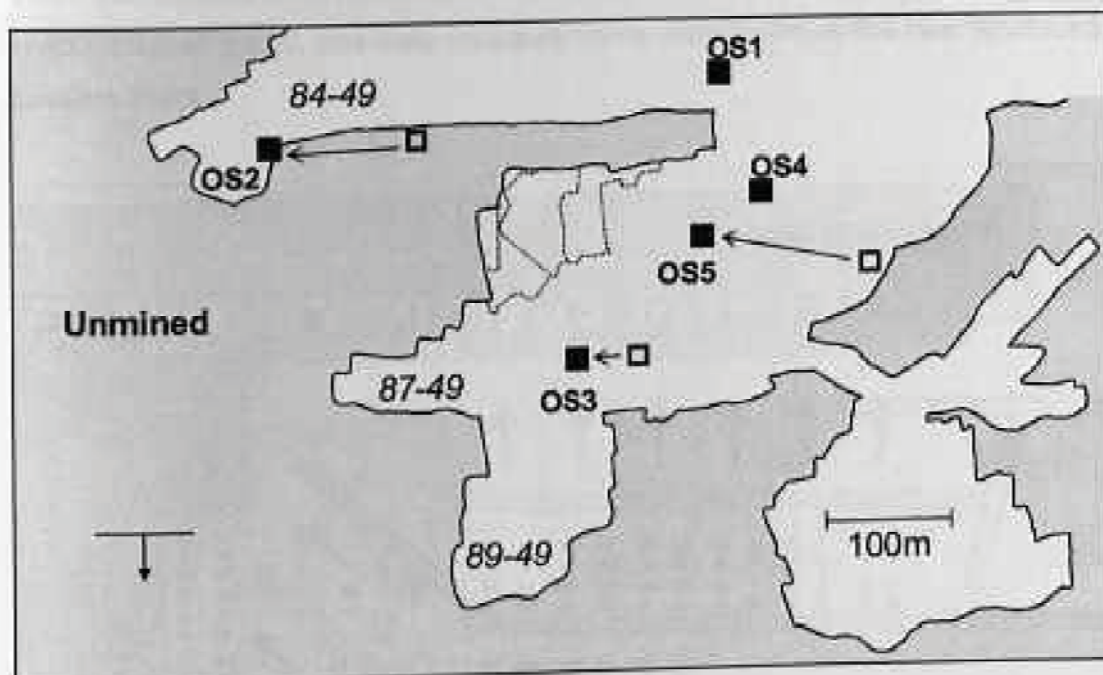


Figure 5.2.8 Plan of a portion of Mponeng gold mine, showing the updated configuration of the preconditioning site seismic network

Stress determination

The results from the monitoring programme revealed that the mechanism of preconditioning is one of stress transferral. In order to quantify the effects of preconditioning, it was decided to undertake direct measurements of stress transfer ahead of an advancing face. The measurements would be taken in a highly stressed and fractured rockmass and consequently the suitability of various strain measuring instruments would be investigated. However, it was determined that none of the available instruments could be used reliably. There was a need for a specially designed instrument that would be suitable for these conditions. A solid inclusion cell was therefore designed and four cells were manufactured.

The instrumentation holes for stress determination were first drilled at about 10-15 m ahead of an updip panel. At a depth of 6-7 m, the very high stresses

encountered made drilling extremely difficult. Eventually, the holes started to collapse, making the installation of the strain gauges impossible. Finally, two of these instruments were installed at around 30 m ahead of an advancing preconditioned panel, and daily measurements were taken as the face advanced towards them.

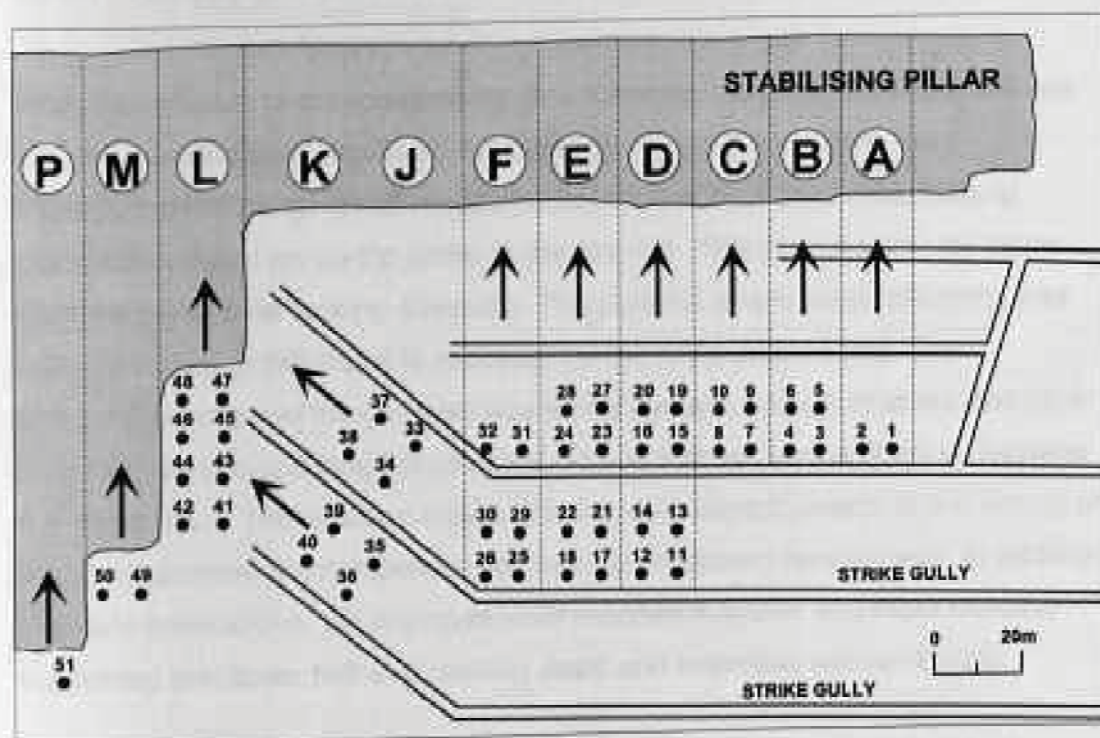


Figure 5.2.9 The relative positions of all convergence stations installed at the project site

Ground motion monitoring

An array of four Ground Motion Monitoring (GMM) devices was installed in the preconditioning site in July 1995. The GMM devices were generally placed close to a convergence station and detailed fracture mapping was carried out around each of the boxes. Hundreds of events were recorded, with about 70 percent of these occurring during blasting time. The maximum peak particle velocity recorded was 780 mm/s. No rockburst damage occurred in the immediate vicinity of a GMM.

5.3 Qualitative analysis of the effects of preconditioning

5.3.1 Ground conditions

After the initiation of preconditioning on a particular panel, it was observed that the ground conditions improved significantly. Figure 5.3.1 shows the improvement of hangingwall conditions before and after the introduction of preconditioning at an up-dip panel at the test site. This photograph was taken from the panel face looking down-dip. The position where preconditioning was first introduced in this panel is indicated by the white dashed line. The preconditioned panel hangingwall was smoother and more competent and safer than the unpreconditioned hangingwall. This statement is quantified in Sections 5.4.4 and 5.5.3. The reduced shake-down due to seismic events in the vicinity of the panel showed the competency of the preconditioned hangingwall. In addition to safety implications, the improvements resulted in easier and more effective supporting practices, reduced stoping costs and improved worker morale.



Figure 5.3.1 The improvement in hangingwall conditions brought about by the introduction of preconditioning

Another example of improved hangingwall conditions in a preconditioned panel is shown in Figure 5.3.2(b). This is compared to an unpreconditioned panel shown in (a). These two photographs were taken in the same panel on the same day. The photograph at (a) shows the down-dip portion of the panel and at (b) the up-dip portion of the panel. This panel was drilled and blasted by two drilling crews, each being responsible for drilling half of the panel. The photographs were taken a few weeks after the introduction of preconditioning into this panel. The difference in hangingwall conditions could be explained by the fact that no preconditioning holes were drilled by the crew mining the panel shown in (a) but the preconditioning holes had been regularly drilled by the crew mining the panel shown at (b).



(a) unpreconditioned



(b) preconditioned

Figure 5.3.2 A comparison of hangingwall conditions in unpreconditioned and preconditioned portion of a panel

When a preconditioned panel was closely examined on the day following a blast, a clean and straight face break shown in Figure 5.3.3 was observed, and there were no or only minimal production-hole sockets. This indicates an effective production blast and a good face advance. The effect of preconditioning on face advance rate is later discussed in Sections 5.4.9 and 5.5.6. It is believed that the face-parallel fractures were opened and extended further into the rockmass by the preconditioning blast and the contact between the reef and hangingwall was separated and remobilised. This resulted in good rock breaking and a reduction in the number of production hole sockets. Few radial blast-induced fractures initiated from each preconditioning blasthole were observed. However, these blast-induced fractures were extended up to and terminated at the contact between the reef and hangingwall or at the contact between the reef and footwall.



Figure 5.3.3 Improved face and hangingwall conditions in a preconditioned panel

5.3.2 Rockburst damage

The primary objective of preconditioning is to reduce the risk of potential facebursts and minimise the damage caused by any seismic event that occurs in the vicinity of the face. During the preconditioning experiment, no faceburst was reported from a preconditioned panel. However, some slight injuries occurred where incorrect or ineffective preconditioning was done and five such cases are described below.

Case 1: A seismic event of magnitude $M=2.0$ was located very close to the West 4 preconditioning panel on 25 July 1995. Although significant damage was observed in West 5 panel, which was not preconditioned, the adjacent preconditioned panel showed no damage at the face or in the hangingwall.

Case 2: The first preconditioning panel had been mined for almost two and a half months over the period 23/5/1995 to 13/8/1995. Owing to preconditioning, a high

face advance rate was achieved in this panel and it reached the planned stop position earlier than expected. The mining activity in two adjacent panels continued towards the stop line at a slower rate. A seismic event of magnitude $M=1.1$, which was located about 30 m from the preconditioning panel, occurred on 31 August 1995. This particular event was associated with a faceburst in the preconditioning panel, which caused some damage at the loose end of the panel and resulted in a fall of ground in the face area. Since the panel had been abandoned two weeks before the event, there was no risk of injury to workers. This event, however, highlights the temporary effects (i.e. transient nature) of preconditioning.

Case 3: A rockburst on 15 February 1996 caused some damage to a diagonal panel (West 2) resulting in injuries to five workers. An event of magnitude $M=1.9$ was located within a few metres of the West 2 diagonal panel. The damage in the West 2 panel comprised falls of ground and significant scaling of the face, but no ejection from the face. In order to investigate further, the preconditioning project team visited the site on the following day.

Extensive falls of ground were observed throughout the panel. Blocks had been ejected from the hangingwall in the area between the face and the first row of packs. The damage was worst in the heading of the diagonal gully where no support was present, and two serious injuries had occurred here as shown in Figure 5.3.4. In this area, blocks of up to 1 m in thickness had fallen from the hangingwall. In the rest of the panel the falls of ground were confined to the area between the face and the line of mechanical props where three other workers were injured. The thickness of the ejected blocks was generally less than 30 cm.

The face was intensively fractured and crushed in some parts of the panel. No face bursting was observed but some reef scaled from the face. This scaling was about 30 cm deep and lay about 1 m from the face. The face had been blasted the day prior to the rockburst and the sockets of both preconditioning and production holes were visible at the face. It was observed that one of the preconditioning holes as shown in Figure 5.3.4 had not been drilled on the day before the rockburst. Since that hole had not been drilled, the distance between the two neighbouring preconditioning holes was almost 6 m. This could have

caused an undesired stress transfer onto that part of the panel, and it was here that most of the damage occurred.

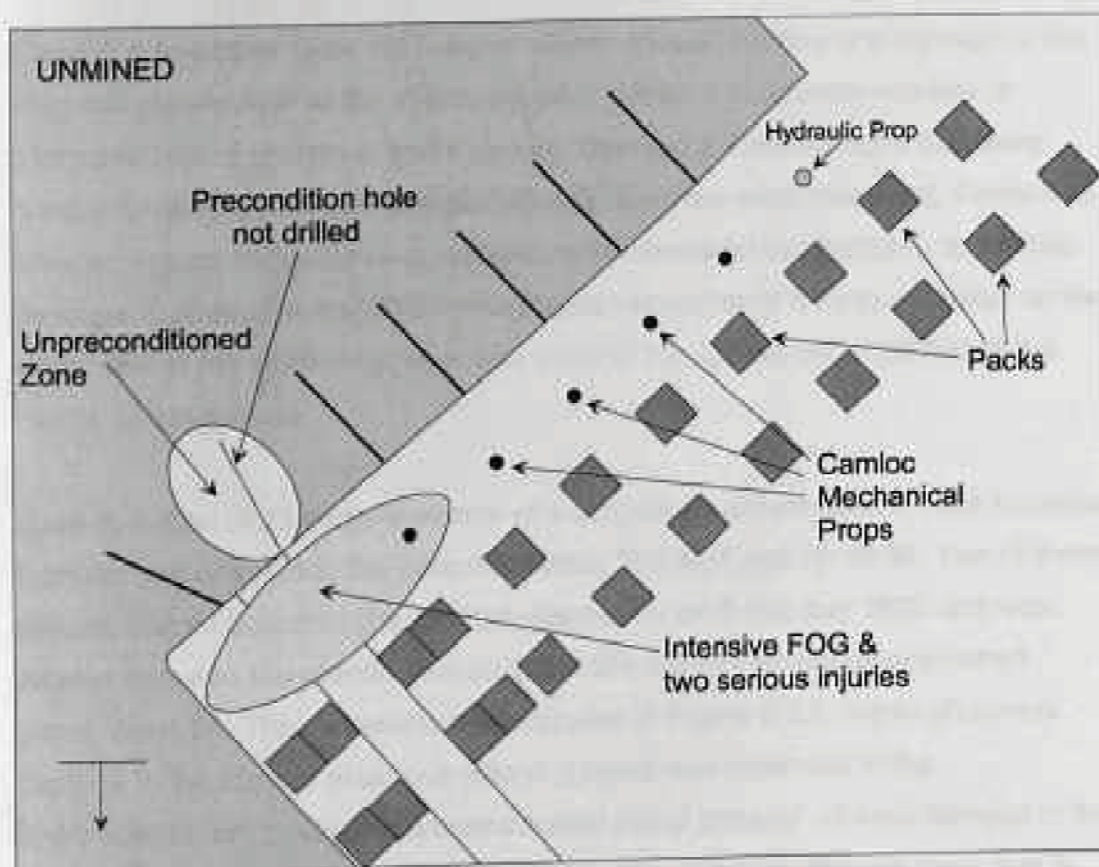


Figure 5.3.4 Schematic plan of West 2 diagonal panel where a rockburst resulted in extensive damage and five injuries (not to scale)

The recommended preconditioning drill pattern for this panel required 3 m long preconditioning holes to be drilled and blasted together with normal 1 m production holes. The objective was to create a 2 m preconditioned zone ahead of the face with every production blast. However, during investigations, it was found that the production holes and the preconditioning holes were drilled 1.5 m long and 2.2 m respectively. Assuming an average of 1.4 m face advance per blast, only a 0.8 m zone ahead of the face was preconditioned. The significantly reduced preconditioned zone ahead of the face may account for the large amount of face scaling that occurred during the rockburst. It was concluded that the panel had not been preconditioned correctly and effectively, but that it had

provided some benefit in preventing what would otherwise, almost certainly, have been a more damaging faceburst.

Case 4: A few other fairly big seismic events caused injuries and damage to the diagonal panels near to the stabilising pillar. Most of the events resulted in extensive falls of ground in these panels. During the investigations that were done after each event poor preconditioning practices were observed. These had resulted in poor hangingwall conditions, with increased susceptibility to seismic damage. Further, the diagonal mining faces caused poor mining geometry on the south side of the stabilising pillar, and most of the injuries occurred during the mining of this ground.

Case 5: A total of 21 seismic events of a magnitude greater than 1 were recorded from the test site during the period between 26/08/96 and 20/10/96. Two of these seismic events occurred virtually simultaneously on 5 October 1996 and were located between the preconditioned panel West 3 and an unpreconditioned panel, West 1A. Their locations are indicated in Figure 5.3.5. Although severe damage in the form of extensive falls of ground was observed in the unpreconditioned panel, the preconditioned panel showed minimal damage in the face and the hangingwall. The production in the unpreconditioned panel had to be stopped for a two-week rehabilitation period as a result of the damage it had sustained. However, production activity continued in the preconditioned panel on the day following the twin seismic events. No injuries were reported as a result of this incident. Four other large seismic events occurred in close proximity to the West 3 panel during the above-mentioned period, none of them causing noticeable damage to the panel.

5.3.3 Workers' perceptions

The benefit of preconditioning is the reduced risk of face bursting. This reduced risk enhances worker morale which, in turn, results in a more efficient workforce. In one stop the preconditioning technique had been referred to by the workforce as "the long holes that stop the burst" and in another, production personnel said they would never go back to working practices that were used prior to the