

7.4 A structured implementation procedure

7.4.1 Preliminary evaluation

Identifying the necessity for preconditioning and its potential benefits is the first and one of the most important actions to be taken before planning any other phases of the implementation. The rock engineering personnel and the senior production personnel, with or without the project team, have to investigate the applicability of preconditioning to the identified workplace. If it is thought that the project team could be involved in this potential implementation case, it is strongly recommended that they be included in the preliminary evaluation.

The investigation team has to clearly state the problem itself, the causes of and the possible solutions to the problem. Even if there is no facaburst problem, the implementation of preconditioning may still be suggested for improving face advance rate, hangingwall conditions, drilling time and fragmentation, and for reducing the potential damage from distant seismic events. If the preconditioning technique is identified as one of the solutions, the rock engineering department has to report the outcome of this evaluation and motivate the implementation of preconditioning to the senior management of the mine. The mine management's approval marks the end of the first step and the initiation of the second step.

7.4.2 Planning of the implementation programme

The same team, now, has to plan the implementation programme in terms of roles and responsibilities of individual departments, timing of the activities and the tools to be used for assessing the effectiveness of preconditioning. Typically, the guidelines set out below can be used.

The rock engineering department's role should be to ensure the correct and continuous application of preconditioning by conducting regular audits and follow-

up visits and assessing and communicating the effects of preconditioning to all parties concerned.

The training department must take an active role in the education and training programme and ensure that the inexperienced personnel be properly trained in preconditioning. They should also take part in follow-up visits, identify any further training needs and address shortcomings in training.

The safety department observers must regularly visit the site and communicate any sub-standard application to the rock engineering department and senior production personnel. They must also analyse the accident statistics and compile regular reports on the effect of preconditioning on the accident records.

The production personnel in supervisory roles must make sure that there is a continuous supply of all required equipment and material into the slope and must provide daily status reports to the rock mechanics department.

Probably the most important achievement during this phase is to have all parties' full commitment to the implementation as was identified as a key success factor.

7.4.3 Education and training seminars and workshops

It is essential to educate the production personnel before attempting to introduce preconditioning in the underground environment. Education must precede training, so that the concept of preconditioning can be "sold" to the workforce by discussing the rock-related problems they experience underground and then demonstrating that preconditioning is part of the solution. This is preferable to a top-down approach whereby preconditioning is simply added to their workload without them being convinced of the benefits to them personally. The workers need to be made aware of what preconditioning is, why they will be using it and what the benefits to them will be, as well as how to apply preconditioning correctly.

A training scheme for the implementation of preconditioning was developed from the experience gained at research sites and was tested in practice from the involvement in a number of implementation cases. This training scheme is aimed at all relevant personnel, namely: management, the rock engineering department, the training department, the safety department and all levels of the production personnel. Instruction is conducted both on surface and underground. Mine training personnel need to be included in the process so that they can continue the training after the introductory implementation period. Similarly, rock engineering and safety department personnel also need to be included, so that they can assess the effects of preconditioning and follow up on the application of preconditioning at underground sites.

During the education programme, the point should be made that preconditioning is likely to be beneficial in more than one way, as improved safety is generally accompanied by increased productivity. It is important to dispel at the outset the notion that preconditioning is simply extra work. A separate bonus payment may not be necessary as an extra production bonus is indicated for extra face advance brought about by effective preconditioning. This would have to be convincingly explained. However, the continuity of proper application may be secured by an incentive bonus payment that can easily be covered by the overall gain in profits resulting from increased productivity. This overall economic benefit was quantified and documented in section 5.4.10.

Education and training (Appendix C) are divided into sections, as follows:

- Introduction.
 - The faceburst problem: what it is, how it arises, what the effects might be and how it can be controlled.
 - Preconditioning: what it is, how it works and what the benefits are expected to be.
- Choosing the appropriate preconditioning method.
 - Face-perpendicular preconditioning: normal mining faces.
 - Face-parallel preconditioning: special areas (remnants, pillars).
- Implementing preconditioning.
 - Guidelines for correct implementation.

- The importance of correct application and the consequences of poor application.
- Assessing the effectiveness of preconditioning.
 - Tools available for making the assessment.

The level of detail and specific emphasis in each section would obviously vary according to the audience, whether slope crew or management. The slope crew would be exposed to less background detail, with more emphasis being placed on the observable and measurable benefits of preconditioning and how to carry out the preconditioning in the underground environment.

Clearly, such issues as language of instruction need to be considered. The instructor should ideally be able to converse with each audience in their mother tongue. The instructor should ideally also be completely familiar with the working environment to which the audience is exposed.

7.4.4 Risk assessment

Prior to the actual implementation of preconditioning, a proper risk assessment must be carried out. The inclusion of production personnel is strongly recommended as this process will re-emphasise the requirement for correct application and the potential danger if preconditioning is not correctly applied. The inspectorates from the Department of Minerals and Energy (DME) will also insist on risk assessment prior to the implementation of the technique. This process should not be seen as additional work or as a burden but rather as a learning opportunity, and extra care must be taken before the implementation of preconditioning in a new geotechnical area. An example of a risk assessment on preconditioning is given in Appendix D.

7.4.5 On-the-job training

An expert team must assist the production personnel during the initial stages of implementation. Proper training on positioning, drilling, charging-up and tying-up

procedures for preconditioning hole(s) should be provided. Good preconditioning practices at other stopes in the same mine must be shown to the new team as part of the training programme. It is recommended that this underground training be given to all affected personnel. When training the workforce underground, it is important to be able to substantiate any claims made about the benefits of preconditioning. These benefits could be demonstrated by measuring the face advance before and after the introduction of preconditioning. A lack of production hole sockets in the face after a blast where preconditioning is used is also a useful indicator of improved face advance. The reality that an increased production bonus could be the result of preconditioning can then be established. Similarly, using work study techniques to determine the drilling time will show that while more drilling activity is required with preconditioning, less time is spent on the whole drilling procedure when compared to the time spent on drilling of production holes alone (i.e. without preconditioning).

The importance of correct application must be re-emphasised and the production personnel have to be made aware of the potential dangers of sub-standard application. This phase of the Implementation process can only come to an end when the expert team for Implementation is satisfied that the production personnel are capable of continuing the correct application of preconditioning. For face-perpendicular preconditioning this period is typically 2-3 cycles of preconditioning (6-9 blasts), whereas for face-parallel preconditioning this period can be longer as the blast optimisation and the integration of this technique into the actual production cycle are relatively more difficult.

7.4.6 Follow-up and assessment of the results

An initial involvement of the expert Implementation team during this phase is also recommended. This phase involves establishing regular follow-up and control mechanisms to ensure the continuation of regular and correct preconditioning application, and these mechanisms should never be discontinued until the mining activities come to an end at that particular stope. While safety control officials and senior production personnel are ensuring the regular and proper application, the

rock engineering department, with the help of production personnel, can be responsible for the assessment of the results.

In order to ensure that preconditioning will continue in the appropriate manner, it has also been suggested that the production standards be changed to incorporate preconditioning as part of the production blast, rather than addressing preconditioning as a separate issue.

7.5 Summary

The favourable results that had been obtained from the preconditioning experiments in the past have not, on their own, been enough to bring about the widespread utilisation of preconditioning as routine practice in faceburst-prone mining areas. Through an industry-wide survey that included mine employees at various levels (workforce to management) the reasons for failure and the critical success factors in the implementation of preconditioning were identified. On the basis of the results obtained from this study the guidelines for the best implementation of preconditioning were produced and a structured implementation process was proposed.

8 DISCUSSION AND CONCLUSIONS

8.1 Effects of preconditioning blasts in confined rock

To design an effective preconditioning blast, one of the important issues is the choice of explosive. It is necessary to consider the amount of explosive energy imparted to the rock and the energy partitioning that occurs in the rock. The gas / shock ratio will have an effect on the preconditioning mechanics. If blasting is to be carried out within the fracture zone a more gassy explosive will result in better gas penetration into existing fractures.

The recorded peak accelerations were highest closest to the blast and decreased with increased distance from the blasthole. Relative to the ANFO type of explosives, greater shock energy was imparted to the rock by emulsion explosives which give higher accelerations close to the blast but which decrease rapidly away from blasthole. The rate of attenuation in peak acceleration in an ANFO blast is much lower than that in an emulsion blast. The lower rate of attenuation in peak acceleration shows that a larger volume of rock should be affected by an ANFO blast. Emulsion explosive is impact resistant and it is easy to use when charging but it has the disadvantage of having lower gas-energy content than ANFO. Since the ANFO-type of explosives give higher accelerations away from the blasthole because of their gaseous character they can be considered as more suitable for use in preconditioning practices.

Explosive in-hole density is a critical design parameter for large face-parallel preconditioning blasts carried out by ANFO-type explosives. Test blasts in holes of 90 mm in diameter revealed that the minimum explosive in-hole density should be about 1100 kg/m^3 (i.e. 7 kg/m).

During the initial investigations, only clay or bentonite types of stemming material were tested and better results were obtained by a bentonite type of stemming.

However, the combination of clay and crushed rock as a stemming material was found to be more effective than the other types tested during actual preconditioning blasts at a later test site.

Preconditioning blasts in confined rock change the stress field by altering the magnitude and the orientation of principal stresses. The maximum principal stresses are increased and the minimum principal stresses are decreased as a function of distance to the blasthole. The directions of principal stresses are rotated through almost 90 degrees. In most cases the maximum principal stress direction becomes almost parallel to the bedding planes after the preconditioning blast. This indicates shear movement along the bedding planes accompanying the blast.

The fracture density is increased with the addition of new fractures, and the pre-existing fractures become more pronounced by widening and extending after the preconditioning blast. The degree of fracture intensification is also a function of the distance to the blasthole.

8.2 Preconditioning techniques

Two different methods of preconditioning have been developed, namely: face-perpendicular preconditioning and face-parallel preconditioning. There seems to be no fundamental rock mechanics reason why either method could not be applied in any given mining environment.

Owing to the very pronounced strain-energy release and stress transfer evident from the seismic data and the significant convergence recorded after the preconditioning blasts, face-parallel preconditioning seems to be the more effective method from a rock mechanics point of view.

The strain-energy release and stress transfer were not distinguishable in the seismic data recorded from the face-perpendicular preconditioning site but a significant increase in convergence rate was recorded after face-perpendicular preconditioning was initiated on a particular panel.

While face-parallel preconditioning is currently the recommended method for pillar extraction its implementation can be difficult under many circumstances because of 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 hinder the application of face-parallel preconditioning. In special areas, however, this may be the only way of safely extracting highly stressed ground and it appears to be an effective method for pillar extraction.

Owing to the difficulty of incorporating face-parallel preconditioning within the mining cycle, there seems to be resistance to using face-parallel preconditioning, even for pillar extraction. At least one example of the implementation of face-perpendicular preconditioning in a pillar extraction scenario proved that even this technique could be very effective in minimising the damage caused by large seismic events.

The rockmass surrounding the portion of a face-parallel preconditioning hole that is not charged but contains the stemming is not effectively preconditioned. It appears that the preconditioning blast can actually result in stress being transferred onto this portion of the rockmass. This is highly undesirable as this region will always be close to a free face and, consequently, adjacent to areas where people have access. Therefore, this area must also be preconditioned by additional face-parallel or face-perpendicular holes integrated into the main face-parallel preconditioning blast.

The implementation of face-perpendicular preconditioning is commonly considered to be more attractive, since it is easier to fit into the mining cycle and the side effects of improving face advance rates have been quantified. Face-perpendicular preconditioning can more easily be applied routinely, without undue concern for panel sequencing and for correct positioning of the preconditioning holes ahead of the face.

The face-perpendicular method does not suffer from the potential adverse effects arising from the need for a substantial length of stemming for face-parallel preconditioning.

Face-perpendicular preconditioning is not without stringent requirements. The most important of these is the dependence of this method on adherence to a strict firing sequence. Out-of-sequence initiation could lead to misfires or to the preconditioning blast's breaking rock, rather than preconditioning it.

It is vital that all face-perpendicular preconditioning holes initiate because if one hole is not blasted for any reason and all of the other holes are blasted, this area could become a stress concentrator by accepting the transferred stress from the preconditioned areas.

When a slope face is being preconditioned, the siding and lead area between panels must not be ignored, as they are also susceptible to bursting. This was addressed with respect to face-parallel preconditioning, to some extent, by drilling the preconditioning holes longer than the face to extend into the adjacent panels. When the face-perpendicular technique was used, additional preconditioning holes were drilled into these susceptible areas.

8.3 Preconditioning mechanism

While very localised blast-induced fracturing was observed around the preconditioning holes in the reef plane, no new fracture groups were found to occur in the hangingwall of the preconditioned panel. If the mechanism of preconditioning was only one of new fracture generation one would have expected to find new fracture groups in the hangingwall of the preconditioned panels. As this is not the case, the most likely mechanism to describe the effect of the preconditioning blast on the rockmass is mainly that of causing slip on pre-existing fractures. There is evidence of re-activation of pre-existing fracture surfaces in the preconditioned panels.

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 gas produced by the

blast penetrating 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 gas is believed to be the dominant mechanism so a high-gas-generating explosive would provide for the most effective preconditioning of the rockmass.

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 transferral. Local readjustments in the state of stress in the zone of fractured rockmass ahead of the face that is subjected to the preconditioning process results in the over-burden load being shifted to adjacent areas of the rockmass outside the direct influence of the preconditioning blast. The benefit to the mining personnel is that a low stressed "cushion" of rock is produced in the immediate stope face. High stress in the immediate face that results in facebursts in non-preconditioned stopes is no longer present and, hence, 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) and does not involve modification of 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.

Of practical significance is that stress transfer is a dynamic and 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 and 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 blasts must be maintained as an integral part of the production blast cycle, which means that every production blast must be accompanied by an effective preconditioning blast.

Although the most controllable effects of preconditioning are local the preconditioning process has a more widespread effect on occasions when large events occur subsequent to a preconditioning blast. This is particularly applicable to face-parallel preconditioning. 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 load from the preconditioned rock onto the adjacent rockmass. However, if this adjacent rockmass was already highly stressed and in a condition of unstable equilibrium then 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 as a 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 equilibrium state, a large local instability is encountered then a large seismic event can be initiated or triggered.

The preconditioning experimentation to date has generally taken place in areas with a reasonably strong and competent hangingwall, with a relatively narrow stoping width. It is possible that large preconditioning blasts may have a detrimental effect on the stability of weaker hangingwall strata. It is expected that future implementation of preconditioning in different areas will provide more insight in this regard.

8.4 Safety and productivity

Both face-perpendicular and face-parallel preconditioning have prevented face bursting in areas to which they have been applied, even though several large seismic events have occurred close to the faces. In addition, less overall damage was observed in the preconditioned panels following these events than in similarly exposed unpreconditioned panels.

The main purpose of preconditioning is to prevent facebursts. Indirectly, it can affect the rockmass in the vicinity through the stress transfer resulting from the blast. Although preconditioning might be beneficial in providing some protection against distant events for the face area, it is not possible to influence the source of such events. Preconditioning cannot control the large-scale behaviour of the rockmass manifested, for example, in the form of instabilities on geological structures or in pillars. It can, however, provide some protection to the face area from distant events, through the capacity of the preconditioned ground to absorb energy that might otherwise lead to in-stope damage.

An improvement in hangingwall stability has generally been noted in preconditioned areas. Fracture mapping has indicated that a reduction in the prevalence of adversely-oriented fractures was probably the major contributing factor to this improvement.

In addition to the safety aspects of preconditioning a significant increase in the face advance rate, consistent with the improved fragmentation, has also been noted. During preconditioning the average face advance rate increased by almost 50 percent. This increase meant that the mining cost per area decreased about 15 percent.

The effect of preconditioning on improving the drilling rate of production holes was also significant.. Where the total drilling times were compared in unpreconditioned and preconditioned panels, it was shown that less time was actually spent for drilling in preconditioned panels, despite the fact that more metres were drilled. Higher drilling rates were achieved when the amount of explosive in the preconditioning holes was increased.

8.5 Optimisation of preconditioning

The differences in results obtained by varying the blast parameters for face-perpendicular preconditioning were less significant than the clear positive differences observed when comparing preconditioned areas with non-preconditioned areas. However, in order to maximise the effectiveness of preconditioning, it is advisable to optimise the blast parameters when preconditioning is implemented in new environments. Practicality and suitability should be the major concerns. Compromising the optimal preconditioning application somewhat is preferable to disrupting the mining activity unnecessarily.

When considering drill-steel lengths, optimal results were achieved for face-perpendicular preconditioning holes drilled with 3.2 m long drill-steels. Drill-steels of this length yielded the best face advances, if only marginally better than those from 3.6 m drill-steels. The latter drill-steels did show slightly higher drilling rates, but required longer manoeuvring times. The relative practical merits of using the 3.2 m drill-steels in the confined space of a stope face also outweighed whatever improvement in preconditioning effect might have been derived from the longer drill-steels. The use of 2.4 m drill-steels is not recommended, although preconditioning even with the shorter drill-steels is more beneficial than no preconditioning at all.

The use of a 40 mm diameter drill-bit with the 3.2 m long drill-steel yielded somewhat improved results. However, potential practical problems that could be encountered when using drill-bits of two different sizes in the stope may outweigh the potential gains of using the larger bits. Therefore, the use of drill-bits of the same diameter as those used to drill the normal production holes is recommended for drilling the preconditioning holes, in order to facilitate the successful integration of preconditioning into the production routine.

Analysis and interpretation of the GPR data indicated that the effective zone around each face-perpendicular preconditioning hole extends 2 m along the stope face. Thus, a maximum spacing of 4 m between preconditioning holes is recommended for effective preconditioning of the whole length of the stope face. This should prevent the formation of hard patches of locked-up fractures ahead of

the face, which could attract stress concentrations that lead to an increased risk of face bursting. In practice, the spacing between adjacent preconditioning holes is influenced by the spacing between packs at the face, but it is important that this should not be allowed to result in an increase in the hole spacing to beyond the recommended maximum.

The seismicity, convergence measurements and fracture-mapping data, when used to compare the characteristics of preconditioned and non-preconditioned areas of the stope, have contributed valuable insights into the efficacy and mechanisms of preconditioning. However, these data sets have thus far not revealed significant differences among the results from the use of the various face-perpendicular preconditioning parameters.

Hangingwall profiling has proved to be a very valuable tool in quantifying the improved underground conditions derived from the use of preconditioning. However, the results obtained from the examination of hangingwall profiles conducted as part of the optimisation study were ambiguous. Nevertheless, the results suggested that the use of larger-diameter drill-bits might provide for more effective preconditioning.

After a proper and regular implementation in high-stoping-width-areas, it was observed that preconditioning provided a safer working environment in terms of protecting the mining faces from potential facebursts. However, overhanging face shapes could not be eliminated when the preconditioning holes were drilled in the middle of the stope height (i.e. equal or greater than 1 m from the contact between the reef and hangingwall). When preconditioning holes were positioned at about 60 cm below the contact between the reef and hangingwall overhanging face shapes were eliminated and improved hangingwall conditions were observed. In addition, the production personnel reported that the face advance per blast was increased after the introduction of preconditioning.

8.6 Implementation of preconditioning

Preconditioning has been effective in enabling safer mining in seismically hazardous areas, wherever it has been implemented correctly under suitable conditions.

Owing to a fundamental lack of understanding of preconditioning, certain mines have been trying to implement preconditioning under inappropriate conditions or to solve problems to which preconditioning is not suited. In some places, the use of preconditioning has been discontinued because of the resistance from production personnel, which has resulted entirely from the adverse effects of incorrect application.

There is a clear need for an implementation team that can provide assistance in the implementation of preconditioning and the training of personnel on individual mines. Such an implementation team should consist of at least two individuals: one person who understands the fundamentals of preconditioning and another who is familiar with its practical application and can communicate effectively with the workforce in the underground environment.

The education of all production personnel and the training of the slope crew are essential, although these steps may not be sufficient for successful implementation of preconditioning. The knowledge transfer should take place through both education sessions on surface and training sessions in the workplace underground. It is important that regular follow-up take place for a period after the initiation of preconditioning at a site. The mine's safety and training personnel should also be educated and trained so that they can continue the process after the implementation team has been withdrawn.

One of the most important aspects of an effective implementation programme is the education of the workforce prior to the introduction of preconditioning to a new site. The workers must be made aware not only of how to apply the preconditioning correctly and of the need to do so but of the direct benefits to them in their working environment. Therefore, a detailed education and training

scheme has been formulated on the basis of experience gained at the research sites and during involvement with pilot implementation programmes at other sites in the industry.

The stope crew must be convinced of the need to implement preconditioning successfully, rather than viewing preconditioning as an order to be carried out. During the education and training of the stope crew, the direct and indirect implications in terms of bonuses must be clearly explained, as well as the safety benefits of preconditioning. Some additional safety incentive bonuses may be considered to ensure proper implementation of preconditioning since it has been found to be a cost-effective safety measure.

The inclusion of preconditioning as part of the code of practice on a mine is highly recommended. This would enable the mine's safety-control personnel to follow up on compliance with the preconditioning requirement. In addition, audits should be conducted by the mine's rock mechanics personnel.

It is encouraging to see that a significant number of mines have been implementing preconditioning to a lesser or greater degree. It is expected that with this growing pool of experience of the benefits that can be gained from preconditioning, many more mines will start implementation and many more lives will be saved.

8.7 Assessment of the effects of preconditioning

In order to be able to assess the effects of preconditioning it is important to obtain some information regarding rockmass behaviour in a particular stope prior to its introduction or, at least, from a nearby comparable area. This is especially important in an environment in which preconditioning has not been evaluated before. Although intensive monitoring of the sort that was carried out while developing preconditioning is not required for the implementation of preconditioning, sufficient monitoring should be conducted to ensure that preconditioning is effective.

The effects of a properly executed face-parallel preconditioning blast on the panel face are readily apparent. The blast will result in scaling of rock from the face, with minor amounts of shake-out from the hangingwall, the extent of which is dependant on the positioning of the hole and the amount of barring that the face area has undergone. Extensive dilation of the face indicates that a relatively solid face has been displaced into the void of the slope to accommodate the deformation of the rockmass due to the opening up of fractures ahead of the slope face. Such observations are not possible in the case of face-perpendicular preconditioning, where the preconditioning blast is initiated concurrently with the production blast.

Regular examination of the faces and hangingwall should reveal significant differences between conditions before and after the introduction of preconditioning. The face should be softer and easier to bar after blasting and the hangingwall should be smoother after preconditioning has been in use for a period. The shapes of holes drilled into a preconditioned face should be less elongated, reflecting the reduced stress levels acting on the rockmass ahead of the face.

Sufficient seismic coverage should be available prior to and throughout the preconditioning period to enable the evaluation of changes to the recorded seismicity patterns. If the general seismicity patterns of the slope can be evaluated, an understanding of the effects of preconditioning on those patterns can be gained. The effectiveness of preconditioning can also be determined from an analysis of the seismicity directly associated with recorded preconditioning blasts. This, of course, is particularly applicable to situations in which the preconditioning blast is initiated apart from production blasts.

A history of the convergence rates in the slope can facilitate awareness of rockmass response to changing conditions. Variations in convergence can provide indications of increasing strain energy being stored ahead of the slope face. Convergence stations provide the actual convergence within the slope. The profile of these convergence plots is the result of both the geometrical change in the excavation as the face advances and the time-dependent behaviour of the rockmass. The true time-dependent behaviour of the rock can be identified by

using convergence instruments that record in a continuous fashion. This may also be routinely useful in identifying the stress level ahead of the face and the effectiveness of preconditioning blasts.

9 RECOMMENDED FUTURE RESEARCH

Further research should be conducted on the following subjects:

- the development and the optimisation of preconditioning techniques for development ends;
- the effect of preconditioning on intensely bedded and / or highly fractured hangingwall;
- the effect of preconditioning on hangingwalls where there is no distinct parting interface between the reef and hangingwall;
- the drilling of long preconditioning holes in panels where backfill is kept very close to the face;
- the effects and the optimisation of preconditioning for safer remnant extraction; and
- the optimisation of the timing of the face-perpendicular preconditioning blasts for the most effective integration into the production blast.

APPENDIX A: CRITERIA BY WHICH PRECONDITIONING BLASTS WERE JUDGED

Criteria by which preconditioning blasts at Blyvooruitzicht Gold Mine 17-24W pillar preconditioning experiment were judged

These criteria were the result of an attempt to minimise subjectivity in the assessment of the effectiveness of individual preconditioning blasts.

The criteria

1. The seismic magnitude of the recorded blast event: the size of the seismic event recorded by the monitoring PSS network at the time of the blast, related to the amount of explosive used for the blast.
2. The number of seismic events recorded from the site in the 24 hours following the blast: adjusted according to whether or not there was a production blast in another panel on the same day.
3. The largest magnitude of the subsequent seismicity: seismic events of $M \geq 0.0$ indicated additional release of stored strain energy over and above that released by the blast itself.
4. The evidence of spallal migration of the subsequent seismicity: migration of subsequent seismicity away from the site of the blast indicated the effective redistribution of stress in the rockmass by the blast.
5. The convergence recorded on the following day: adjusted according to whether or not the measurement was made in the panel of the blast or in *another panel*, and whether or not there was a production blast in another panel on the same day.

The critical values and rating system

The rating system described below is ordered with the values for a "typical" preconditioning blast given first, followed by those for an underachieving blast and then those for an exceptional blast.

Start with 0 points.

1. Blast magnitude (M_{blast}):

- If M_{blast} lies in the range $(\text{kg explosive}/100)\pm 0.5$, add 1
- If M_{blast} is below this range, add 0
- If M_{blast} is above this range, add 2

2. Number of subsequent events:

- If there was no production blast
 - If there are between 10 and 19 events, add 1
 - If there are fewer than 10 events, add 0
 - If there are 20 or more events, add 2
- If there was a production blast
 - If there are between 20 and 39 events, add 1
 - If there are fewer than 20 events, add 0
 - If there are 40 or more events, add 2

3. Largest subsequent event magnitude:

- If the largest event magnitude is in the range $0.0 \leq M < 1.0$, add 1
- If the largest event magnitude is $M < 0.0$, add 0
- If the largest event magnitude is $M \geq 1.0$, add 2

4. Spatial migration:

- If there is some evidence of migration, add 1
- If there is no evidence of migration, add 0
- If there is convincing evidence of migration, add 2

5. Convergence:

- If the convergence was measured in the panel of the preconditioning blast
 - If the convergence is 15 mm or more but less than 30 mm, add 1
 - If the convergence is less than 15 mm, add 0
 - If the convergence is 30 mm or more, add 2
- If the convergence was measured in another panel and there was no production blast
 - If the convergence is 10 mm or more but less than 20 mm, add 1
 - If the convergence is less than 10 mm, add 0
 - If the convergence is 20 mm or more, add 2
- If the convergence was measured in another panel and there was a production blast
 - If the convergence is 20 mm or more but less than 40 mm, add 1
 - If the convergence is less than 20 mm, add 0
 - If the convergence is 40 mm or more, add 2

Rate the preconditioning blast (i.e. calculate the percentage) out of a possible total of 10 points.

APPENDIX B: SUMMARY INFORMATION FOR EACH PRECONDITIONING BLAST

Preconditioning blast at Blyvooruitzicht Gold Mine 17-24W preconditioning site

Preconditioning blasts in 1992.

Date of blast	Panel number	Mass of explosive (kg)	Explosive type	Length of hole (m)	Length of stemming (m)	Seismic magnitude of blast	Number of events following (24 h)	Longest magnitude of these	Evidence of spatial migration?	Convergence in panel of blast (mm)	Distance to face (m)	Blast rating (%)
09/09/92	2	150	Anfo	17.0	5.0	¹ ?	5	-1.1	?	?	?	--
09/10/92	2	125	Emulsion	17.0	5.0	0.8	35	-0.7	yes	?	?	63
06/11/92	2	150	Anfo	¹¹ 22.0	7.0	¹² 0.9	5	-0.7	?	11	7.1	0
26/11/92	1	75	Anfo	14.0	5.0	0.7	19	-0.3	yes	35	1.0	60
03/12/92	2	150	Anfo	¹¹ 22.0	5.0	1.2	8	1.2	some	16	3.8	50

NOTES:

- ¹ seismic data acquisition problems experienced
- ² event magnitude obtained from BGM mine-wide seismic system
- ³ production blast in panel 1 on same day
- ⁴ production blast in panel 2 on same day
- ⁵ production blast in stub on same day
- ⁶ includes effects of production blast on following day
- ⁷ measured in panel 1
- ⁸ measured in panel 2
- ⁹ blasted same hole again
- ¹⁰ hole drilled too far ahead of face
- ¹¹ drilling difficulties experienced: blockages in holes, etc
- ¹² two holes drilled, one changed
- ¹³ hole diameter 76 mm
- ¹⁴ first attempt misfired

Preconditioning blasts in 1993.

Date of blast	Panel number	Mass of explosive (kg)	Explosive type	Length of hole (m)	Length of stemming (m)	Seismic magnitude of blast	Number of events following (24 h)	Largest magnitude of these	Evidence of spatial migration?	Convergence in panel of blast (mm)	Distance to face (m)	Blast rating (%)
02/01/93	1	75	Anfo	¹⁰ 15.0	5.0	0.2	5	-0.6	yes	7	7.0	20
18/01/93	2	116	Anfo	¹¹ 18.0	6.0	0.8	9	0.4	some	12	4.8	30
22/01/93	Stub	50	Anfo	¹² 10.0	5.0	-0.1	10	-1.0	no	19	5.4	0
18/02/93	1	75	Anfo	15.0	5.0	0.8	43	0.4	yes	?	?	75
02/03/93	2	95	Anfo	15.0	5.0	0.8	20	0.1	no	16	5.8	40
15/03/93	Stub	75	Anfo	10.0	5.0	² 2.0	8	-1.3	some	41	5.6	50
31/03/93	1	81	Emulsion	¹³ 17.0	5.0	0.8	12	0.4	yes	3	2.9	50
18/04/93	2	81	Anfo	¹² 15.0	5.0	0.8	8	-1.0	some	14	2.9	20
14/05/93	1	93	Emulsion	14.0	5.0	0.8	5	-0.8	some	30	3.2	40
07/06/93	2	100	Anfo	16.0	5.0	0.8	22	² 1.8	some	64	4.7	80
29/06/93	1	100	Anfo	14.5	5.0	0.5	2	-1.6	no	4	5.0	10
12/07/93	Stub	43	Anfo	10.0	5.0	0.2	³ 12	-0.1	no	11	2.4	10
19/08/93	1	100	Anfo	13.5	5.0	0.8	16	-0.8	yes	9	4.2	40
30/09/93	2	125	Anfo	18.0	6.5	¹² 1.9	?	?	?	20	2.9	75
04/11/93	1	100	Emulsion	13.5	5.0	1.0	⁴ 57	0.3	some	16	2.3	60
22/12/93	2	100	Anfo	16.5	5.0	1.0	18	-0.9	yes	13	2.3	40

Preconditioning blasts in 1994.

Date of blast	Panel number	Mass of explosive (kg)	Explosive type	Length of hole (m)	Length of stemming (m)	Seismic magnitude of blast	Number of events following (24 h)	Largest magnitude of these	Evidence of spatial migration?	Convergence in panel of blast (mm)	Distance to face (m)	Blast rating (%)
10/01/94	sub	69	Anfo	10.5	5.5	-0.0	9	-0.6	yes	4	4.9	20
17/01/94	1	96	Anfo	13.0	5.0	0.9	29	0.5	some	12	2.2	40
10/02/94	2	100	Anfo	18.0	6.5	-1.1	8	-1.1	no	2	6.4	0
28/02/94	2	100	Anfo	18.5	5.0	1.3	14	-0.3	some	39	3.1	50
17/03/94	1	62	Anfo	12.0	5.0	0.6	12	-0.6	yes	11	4.8	40
11/04/94	sub	50	Anfo	10.0	5.0	0.4	39	0.0	no	26	4.0	40
15/04/94	2	130	Emulsion	20.0	5.0	1.4	11	2.3	some	47	4.3	70
18/05/94	1	75	Emulsion	13.0	5.0	0.8	7	-1.5	some	4	4.3	20
24/06/94	2	138	Anfo	20.0	5.0	1.0	14	-0.2	yes	21	2.7	50
20/08/94	1	80	Emulsion	15.0	5.0	0.8	13	-0.9	yes	13	1.9	40
26/09/94	2	85	Anfo	21.0	5.0	0.8	5	-1.2	some	3	2.3	20
29/09/94	sub	40	Anfo	9.0	5.0	-0.2	17	0.2	no	2	4.7	10
28/10/94	1	75	Emulsion	13.0	5.0	0.9	18	2.1	yes	26	5.6	80
08/12/94	2	100	Anfo	17.5	5.0	0.8	11	0.3	some	15	4.0	50
15/12/94	sub	75	Anfo	11.0	6.5	0.3	21	1.5	yes	19	5.2	80

Preconditioning blasts in 1995.

Date of blast	Panel number	Mass of explosive (kg)	Explosive type	Length of hole (m)	Length of stemming (m)	Seismic magnitude of blast	Number of events following (24 h)	Largest magnitude of these	Evidence of spatial migration?	Convergence in panel of blast (mm)	Distance to face (m)	Blast rating (%)
10/01/95	1	75	Emulsion	13.5	5.0	0.8	19	-0.6	yes	7	2.5	40
03/02/95	2	100	Anfo	20.0	5.0	0.7	26	-0.6	yes	16	4.3	90
06/03/95	1	75	Emulsion	12.0	5.0	0.7	9	-0.7	yes	10	6.9	30
29/03/95	2	75	Anfo	11.2-12.0	2.0	0.3	17	-0.1	some	6	4.3	30
05/04/95	stub	25	Anfo	10.5-13.0	1.0	-0.2	10	-1.0	yes	3	4.3	40
19/05/95	1	40	Emulsion	11.9.0	4.5	0.3	50	-0.6	some	6	4.2	40
01/06/95	2	75	Anfo	10.5-20.0	5.0	0.5	14	0.2	some	7	6.1	30
05/06/95	stub	35	Emulsion	10.5-6.0	2.0	0.0	23	-0.6	no	9	8.6	20
01/08/95	1	50	Anfo	9.0	5.0	0.4	23	-0.5	some	5	2.4	30
09/08/95	2	137	Anfo	20.0	5.0	0.8	50	-0.6	yes	34	3.4	60
18/08/95	stub	25	Anfo	4.5	2.0	-0.5	25	-0.3	no	7	1.5	10
14/23/09/95	1	36	Emulsion	10.0	5.0	0.4	3	-0.9	no	14	2.8	10
04/10/95	2	100	Emulsion	10.2-20.0	6.5	1.0	10	-0.5	no	21	5.2	20
16/11/95	1	50	Emulsion	8.0	9.0	0.5	7	0.8	yes	19	2.1	50
05/12/95	2	100	Emulsion	11-12.0	5.0	0.8	17	0.1	some	11	4.6	30

APPENDIX C: EDUCATION AND TRAINING MODULE

EDUCATION AND TRAINING MODULE

Introduction

In this section, the instructor should explain what preconditioning can be expected to achieve and, as importantly, what it should not be expected to accomplish.

Preconditioning is a rockburst control technique intended to alleviate the effects of potentially damaging seismic events on the stope face areas, with special reference to face ejection type rockbursts. Preconditioning is not a substitute for good mining practice and should be seen as a component of a system of safe mining. Sensible mine planning and adequate support design and installation continue to be important when preconditioning is applied.

The faceburst problem

Preconditioning will generally be applied in faceburst-prone areas, so that the workforce will *usually be familiar with the faceburst problem*, in terms of its effects on ground conditions and production delays in the stope. The instructor would explain the build-up of stresses in the fractured rockmass immediately ahead of the advancing stope faces *and that the rockmass bursts when these stresses exceed the load-bearing capacity of the rockmass*. The faceburst problem is the physical manifestation of high face stresses. What is needed is some means of reducing the amount of stress *acting on the stope faces*.

Preconditioning

The main goal of preconditioning is to increase worker safety by reducing the frequency and severity of face bursting and by reducing the potential for rockburst damage at the stope faces. *Preconditioning makes use of explosives in the fractured rock ahead of mining stope faces to create a destressed zone immediately ahead of the preconditioned face through stress transfer away from the face and, possibly, to trigger larger events off-shift. Generally, it has been*