Criteria for preconditioning at varying stoping widths in different geotechnical areas


Research agency : Rock Engineering Programme, CSIR Division of Mining Technology
Project number : GAP 811
Date : April 2003
Executive summary

Following the completion of the research projects GAP030 and GAP336 certain mines have tried to implement the technique in faceburst-prone high stoping width areas but unfortunately these attempts were claimed to be unsatisfactory. The issue of why the current design of the technique could not meet the faceburst control requirements for these areas or whether the preconditioning technique was incorrectly implemented in those areas was unknown.

A few experimental sites were established in high stoping width areas and the research team ensured that preconditioning was implemented regularly and properly in these sites. After a certain period of regular and continuous preconditioning at these sites, 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 reef / hangingwall contact). When preconditioning holes were positioned at about 60 cm below the reef / hangingwall contact, overhanging face shapes were eliminated and improved hangingwall conditions were observed. The production personnel reported that the face advance per blast was increased after the introduction of preconditioning.

The temporal and spatial distribution of micro-seismic events following face-perpendicular preconditioning was studied to evaluate the effect of preconditioning on face induced seismicity. Two underground stopes, 109/48 and 109/51 at Mponeng mine were monitored during the course of this project.

The temporal distribution of the number of events after preconditioning blasting was found to be similar for both monitoring sites, 109/48 and 109/51, Mponeng mine. The only difference was the longer decay time at site 109/51 indicating that the mining layout may influence the post preconditioning seismicity.

The spatial migration of the seismic events after the preconditioning blasts was obtained for both sites. Most of the seismic events moved up to 15 m ahead of the face. This occurred within the first 10 minutes after the blast, which can be used as an indicator of the time for relaxation or transfer of stresses after the preconditioning blasts. This time
was found to be faster than the relaxation or transfer of the stresses after the production blasts reported in previous studies.

Geological and geotechnical mapping studies of the high stoping width preconditioning sites has shown that preconditioning was effectively used at higher stoping widths. In addition, this study has also shown that preconditioning improves rockmass conditions when a potentially dangerous feature such as a dyke is encountered during stoping operations. These improvements include an increase in the number of face-parallel fractures (which act as a barrier to absorb the seismic energy of a rockburst and thus reduce the potential of face bursting) and an increase in the shearing along the stope hangingwall contact, resulting in fewer fractures penetrating into the hangingwall. This reduces the potential for fall of grounds and reduces dilution.

The major problems associated with the implementation of preconditioning were identified. Much has been learned from this recent study of preconditioning in the mining industry in terms of issues that need to be addressed in order to ensure successful future implementation of the technique. Based on the results obtained from this study the guidelines for the best implementation of preconditioning were updated and a structured implementation process was proposed.

A booklet and a CD-based interactive training module for demonstrating the correct implementation of the preconditioning technique were produced to help the training departments of mines to continue the education and training process.

It is encouraging to see that a significant number of mines are now evaluating or 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, including those mines where remnant extraction forms a significant proportion of total production.
Acknowledgements

The authors of this report (i.e. the CSIR: Mining Technology Preconditioning Research Team) gratefully acknowledge that the work reported here results from funding provided by SIMRAC as Project GAP811. Gratitude goes to the SIMRAC committee members for their enthusiastic support of this preconditioning research project over the last two years.

The work has enjoyed the co-operation of the South African gold mining industry and, in particular, that of Mponeng Gold Mine where the main research sites were situated. The team would like to thank the management of Mponeng Gold Mine for their co-operation in allowing the field sites to operate on their mines. In addition, we would like to express our gratitude to all the personnel on these mines (i.e. Rock Mechanics Department and production personnel) who have given us much needed assistance during the course of our field experiments. Without the help of the people on the mine, this work would not have been possible.
## Table of contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive summary</td>
<td>2</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>4</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>12</td>
</tr>
<tr>
<td>1.1 Research problem</td>
<td>12</td>
</tr>
<tr>
<td>1.2 Objectives and aims of this study</td>
<td>13</td>
</tr>
<tr>
<td>1.2.1 Main objectives</td>
<td>13</td>
</tr>
<tr>
<td>1.2.2 Goals</td>
<td>13</td>
</tr>
<tr>
<td>1.3 Research design</td>
<td>14</td>
</tr>
<tr>
<td>2 IMPLEMENTATION OF PRECONDITIONING IN HIGH STOPING WIDTH AREAS</td>
<td>15</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>15</td>
</tr>
<tr>
<td>2.2 Faceburst problem in high stoping width areas</td>
<td>15</td>
</tr>
<tr>
<td>2.3 Preliminary design of preconditioning technique for high stoping</td>
<td>16</td>
</tr>
<tr>
<td>2.4 Site investigations</td>
<td>18</td>
</tr>
<tr>
<td>2.4.1 Mponeng Gold Mine 94/44 VCR stope</td>
<td>18</td>
</tr>
<tr>
<td>2.4.2 Mponeng Gold Mine 109/48 VCR stope</td>
<td>19</td>
</tr>
<tr>
<td>2.4.3 Mponeng Gold Mine 109/51 VCR stope</td>
<td>21</td>
</tr>
<tr>
<td>2.5 Other implementation sites</td>
<td>23</td>
</tr>
<tr>
<td>2.5.1 Kloof Gold Mine, 7 shaft</td>
<td>23</td>
</tr>
<tr>
<td>2.5.2 Driefontein Gold Mine, 4 East shaft</td>
<td>25</td>
</tr>
<tr>
<td>2.5.3 Tau Tona Gold Mine</td>
<td>25</td>
</tr>
<tr>
<td>2.5.4 Driefontein Gold Mine, 1 East shaft</td>
<td>26</td>
</tr>
<tr>
<td>2.5.5 South deep (Placer Dome) Gold Mine</td>
<td>26</td>
</tr>
<tr>
<td>2.5.6 Savuka Gold Mine</td>
<td>27</td>
</tr>
<tr>
<td>3 STUDY THE TEMPORAL DISTRIBUTION AND SPATIAL MIGRATION OF SEISMICITY</td>
<td>28</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>28</td>
</tr>
<tr>
<td>3.2 Analysing technique</td>
<td>28</td>
</tr>
<tr>
<td>3.2.1 Temporal distribution</td>
<td>28</td>
</tr>
<tr>
<td>3.2.2 Spatial migration</td>
<td>29</td>
</tr>
<tr>
<td>3.3 Site descriptions and results</td>
<td>30</td>
</tr>
<tr>
<td>3.3.1 Site 109/48 VCR stope at Mponeng Gold Mine</td>
<td>30</td>
</tr>
</tbody>
</table>
3.3.2 Temporal distribution of the seismic events at site 109/48 VCR stope at Mponeng mine ................................................... 31
3.3.3 Spatial migration of the seismic events at site 109/48 VCR stope at Mponeng Gold Mine ................................................... 34
3.3.4 Site 109/51 VCR stope at Mponeng Gold Mine ................. 35
3.3.5 Temporal distribution of the seismic events at site 109/51 VCR stope at Mponeng mine ................................................... 36
3.3.6 Spatial migration of the seismic events at site 109/51 VCR stope at Mponeng Gold Mine ................................................... 38
3.3.7 Discussion ............................................................................... 40

4 GEOLOGICAL AND GEOTECHNICAL MAPPING ....................................... 41
4.1 Preconditioning site at Mponeng gold mine .......................................... 41
4.2 Preconditioning site at Savuka gold mine ............................................. 46
4.3 Preconditioning site at Driefontein gold mine ....................................... 50
4.4 Unpreconditioned site at Savuka gold mine ......................................... 54
4.5 Summary .............................................................................................. 55

5 IMPLEMENTATION OF PRECONDITIONING ............................................. 56
5.1 Introduction ........................................................................................... 56
5.2 Problems associated with the implementation of preconditioning..... 56

6 GUIDELINES FOR THE IMPLEMENTATION OF PRECONDITIONING ..... 65
6.1 A structured implementation process ................................................... 65
6.1.1 Preliminary evaluation ......................................................................... 65
6.1.2 Planning of the implementation programme ................................... 66
6.1.3 Education and training seminars/workshops .................................... 66
6.1.4 Risk assessment ................................................................................. 68
6.1.5 On the job training ............................................................................. 68
6.1.6 Follow-up and assessment of the results ........................................... 69

7 GUIDELINES FOR FACE-PERPENDICULAR PRECONDITIONING ........ 71
7.1 Introduction ........................................................................................... 71
7.2 Drilling preconditioning holes ............................................................... 73
7.3 Charging preconditioning holes ............................................................. 75
7.4 Stemming ............................................................................................... 76
7.5 Handling of misfires and sockets ............................................................ 78

8 CONCLUSIONS ............................................................................................ 79
References ............................................................................................................ 82
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix A</td>
<td>83</td>
</tr>
<tr>
<td>Education and training</td>
<td>83</td>
</tr>
<tr>
<td>Appendix B</td>
<td>92</td>
</tr>
<tr>
<td>Example of risk assessment</td>
<td>92</td>
</tr>
</tbody>
</table>
Table of figures

| Figure 2.1 | The process followed for the solution of this research problem | 17 |
| Figure 2.2 | The project site 109/48 VCR stope at Mponeng Gold Mine | 20 |
| Figure 2.3 | Improved hangingwall conditions where the preconditioning hole was drilled at about 60 cm below the reef / hangingwall contact | 21 |
| Figure 2.4 | Overhanging hangingwall conditions where the preconditioning hole was drilled at a distance greater than 1 m below the reef / hangingwall contact | 22 |
| Figure 2.5 | Improved hangingwall conditions where the preconditioning hole was drilled at about 60 cm below the reef / hangingwall contact | 23 |
| Figure 2.6 | Overhanging hangingwall conditions where the preconditioning hole was drilled at a distance greater than 1 m below the reef / hangingwall contact | 24 |
| Figure 3.1 | The schematic view of the mining layout and recording configuration at 109/48 stope at Mponeng Gold Mine | 31 |
| Figure 3.2 | Decay of the seismicity with time following the preconditioning blasts in panel E1 | 33 |
| Figure 3.3 | Cumulative number of events as a function of time for panel E1 | 33 |
| Figure 3.4 | Spatial migrations of the seismic events along the face | 34 |
| Figure 3.5 | Spatial migrations of the seismic events ahead of the face | 35 |
| Figure 3.6 | A schematic diagram illustrating the position of the recording configuration installed at stope 109/51 at Mponeng Gold Mine | 36 |
| Figure 3.7 | Decay of the seismicity with time following the preconditioning blasts | 38 |
| Figure 3.8 | Cumulative number of events as a function of time | 38 |
| Figure 3.9 | Spatial migrations of the seismic events along the face | 39 |
| Figure 3.10 | Spatial migrations of the seismic events ahead to the face | 39 |
| Figure 4.1 | Mapped areas at the preconditioning site at Mponeng mine | 42 |
Figure 4.2  Sketch-map showing the orientation of the mapped discontinuities ................................................................. 43

Figure 4.3  Lower hemisphere, Schmidt-net projection of the mapped discontinuities. The position of the fractures is indicated by letters, R = reef, H = hangingwall and F = footwall. Arc indicates the orientation (great-circle) of the face ....................... 44

Figure 4.4  Histogram of the discontinuity frequency of the footwall, hangingwall and reef ............................................................... 45

Figure 4.5  Mapping of the reef horizon on the eastern side of the stope. Ellipses indicate fall of ground areas ......................... 45

Figure 4.6  Map showing the position of the mapped sections and hangingwall profiles ................................................................. 46

Figure 4.7  Face profiles of the mapped area. Note the lack of hangingwall and footwall exposure and the presence of dyke in profile C ................................................................. 47

Figure 4.8  Photograph showing the intense face-parallel fracturing within the reef ................................................................. 48

Figure 4.9  Frequency of discontinuities .......................................................... 49

Figure 4.10  Photograph showing smooth hangingwall and intensely fractured reef ................................................................. 49

Figure 4.11  Hangingwall profiles within the Tarentaal Dyke and on the reef plane (measurements are in centimetres) ......................... 50

Figure 4.12  Map showing the orientation of the discontinuities and profile positions ................................................................. 51

Figure 4.13  Reef profiles indicating the various rock types present and the numbering used to describe the discontinuity positions ............ 52

Figure 4.14  Hangingwall profile (see Figure 4.12 for position and orientation – the y-axis scale is in millimetres and the x-axis scale is in centimetres) ................................................................. 53

Figure 4.15  Summary of mapping results .......................................................... 54

Figure 7.1  Diagrams showing the face-perpendicular preconditioning layout for a three-day cycle ................................................................. 72

Figure 7.2  Face-perpendicular preconditioning layout for various mining layouts ................................................................. 73
Figure 7.3  Cross-section ahead of the stope face, illustrating the relative positions of the production and preconditioning holes.................................................................................................. 74

Figure 7.4  Hand-held percussion drill machine.............................................................. 75

Figure 7.5  Examples of the recommended tie-up configuration of (a) fuse and igniter cord or electric (b) Nonel for integrating the blasting of preconditioning and production holes................................. 77
## List of tables

| Table 3.1 | Summary of the preconditioning blasting sequences at 109/48 stope, Mponeng Gold Mine | 32 |
| Table 3.2 | Summary of the preconditioning blasting sequences at 109/51 stope, Mponeng Gold Mine | 37 |
| Table 4.1 | Hangingwall profile values for dyke and reef | 50 |
| Table 4.2 | Discontinuity characteristics | 52 |
| Table 4.3 | Characteristics of the hangingwall profile measured | 53 |
1 INTRODUCTION

Facebursts resulting from mining-induced seismicity are a continual hazard in the deep-level gold mines of South Africa. According to the accident database compiled by CSIR/Miningtek under SIMRAC project GAP 330, a significant percentage of fatalities resulted from faceburst incidents throughout the industry.

CSIR/Miningtek has undertaken an extensive research programme to address the issue of rockburst control over a number of years. A considerable amount of knowledge and experience has been gained in the area of preconditioning of stope faces (GAP030 & GAP336).

Two different preconditioning techniques were developed, namely face-perpendicular preconditioning and face-parallel preconditioning. Due to practical limitations, the implementation of the face-parallel method can be difficult under many circumstances, so that its recommended use is generally limited to special areas. The face-perpendicular preconditioning can usually be readily integrated into an existing mining cycle, without any disruption to production. However, both techniques 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 some areas. In addition, minimal overall damage was observed in the preconditioned panels following these events, compared to similarly exposed unpreconditioned panels. Preconditioning has also provided some protection to the face area from distant events, through the capacity of the preconditioned ground to absorb energy. An improvement in hangingwall stability and face advance rate has also been noted in preconditioned areas (Toper, et al, 1998).

1.1 Research problem

Although the preconditioning techniques were developed at different project sites and the face-perpendicular preconditioning technique was successfully implemented at various other sites, the work focused primarily on narrow stoping widths. Following the completion of the research projects (GAP030 & GAP336) certain mines have tried to implement the technique in faceburst-prone high stoping width areas but unfortunately these attempts were claimed to be unsatisfactory. The issue of why the current design of the technique could not meet the faceburst control requirements for these areas or whether those implementation attempts were unsatisfactory was unknown. There was a clear need for re-establishing the best preconditioning practice and formulating the
guidelines for high stoping width mining activities in different geotechnical areas where facebursting has become a problem.

Most important of all, in order to achieve successful technology transfer, the education of all production personnel and the training of the stope crew are essential. The knowledge transfer should take place both via education sessions on surface and training sessions in the workplace underground. It is important that regular follow-up should take place for a period after the initiation of preconditioning at a site. The mine's safety and training departments' personnel should also be educated and trained, so that they can continue the process after the implementation team has been withdrawn.

A booklet and a CD-based interactive training module for demonstrating the correct implementation of the preconditioning technique would help the training departments of mines to continue the process.

1.2 Objectives and aims of this study

1.2.1 Main objectives

The main objectives of this research project were to:

- investigate the reasons behind why the current design of the technique could not meet the faceburst control requirements at high stoping width areas,
- identify the blast parameters that need to be modified and optimised for these areas,
- update the preconditioning guidelines for varying stoping widths, and
- transfer the technology.

1.2.2 Goals

The primary output from this research project is the optimisation of preconditioning at high stoping widths in different geotechnical areas and updating the guidelines for preconditioning in these areas.

In addition to the aims above, the intention of this project is to:
• list the measures to determine the effectiveness of the preconditioning technique,
• consolidate the recommendations on how best this technology can be transferred to the industry, and
• produce a CD-based interactive training module and a booklet for demonstrating the technique.

1.3 Research design

SIMRAC Project GAP811 was designed as a two-year project with the following methodology:

• determination of faceburst control requirements for high stoping width areas in VCR and C/L stopes,
• preliminary design of preconditioning techniques best suitable for high stoping widths in different geotechnical areas,
• implementation of preconditioning techniques in selected underground sites,
• optimisation and final guidelines for preconditioning techniques for high stoping widths in different geotechnical areas,
• technology transfer, and
• final report.
2 IMPLEMENTATION OF PRECONDITIONING IN HIGH STOPING WIDTH AREAS

2.1 Introduction

Research carried out by CSIR Miningtek for SIMRAC showed that the preconditioning technique was very effective in minimizing facebursts and increasing productivity (Lightfoot et. al. 1996 and Toper et. al. 1998). Wherever it was implemented properly, preconditioning also resulted in improved hangingwall and face conditions as well as better fragmentation and improved worker morale. In addition, the technique was found to be cost effective due to the increased face advance per blast (Lightfoot et. al. 1996 and Toper et. al. 1998). However, it was also observed that, following a successful implementation of preconditioning and withdrawal of the implementation team from the site, preconditioning activities tended to be terminated. In addition to those sites that were run with the project team’s involvement, some other mines have implemented preconditioning at different places in the last few years. Some of these attempts were reported as unsuccessful.

2.2 Faceburst problem in high stoping width areas

Facebursting is still one of the major causes of the rock related accidents at certain gold mines. It was reported by the Rock Mechanics Department of a gold mine in the West Rand region that as many as two thirds of their rock related accidents originated in high stope width areas which account for only about 10% of current production. Preconditioning was being carried out in 40% to 50% of high stoping width areas mostly to facilitate the replacement of the double-cut mining method with a single-cut method. The main purpose of the preconditioning was to reduce the increased face bursting which occurred with the single cut method. However, current preconditioning results were reported to be unsatisfactory possibly because the preconditioning technique was unable to effectively address the facebursting problems in these areas.

It was not clear whether this apparent lack of success was a result of deficiencies in the preconditioning method developed for low stoping widths, when applied in high stoping widths, or whether the disappointing results were due to poor implementation. It was thought that some modifications of the preconditioning technique might be required for
high stoping width areas. Based on the findings of SIMRAC project GAP336, there is no known reason why the current technique should not be effective in any stoping width conditions. However, it was recommended that the technique might have to be modified slightly to optimise results where mining conditions are significantly different.

During preliminary underground visits to the high stoping width areas, it was observed that the drilling crews had difficulties in drilling the top row of production holes and the majority of hangingwall instability problems were caused by poor drilling practices. In addition to that, although it was reported that every production blast was accompanied by a preconditioning blast, no preconditioning hole sockets were observed on the face. This proved that at least the last two production blasts were not accompanied by the preconditioning blasts.

### 2.3 Preliminary design of preconditioning technique for high stoping width areas

These preliminary visits to the high stoping width areas revealed two main possibilities that could be responsible for this apparent lack of success:

- poor implementation of preconditioning, and
- potential deficiencies in the preconditioning technique.

Based on these possibilities, the following questions were posed:

1. Were preconditioning holes drilled and blasted with every production blast?
2. Were preconditioning holes positioned, drilled, charged and timed properly?
3. Do we need to modify the preconditioning blast parameters such as, length, diameter, spacing and positioning of holes, and the type and amount of explosives?

It was then decided that two experimental sites would be established in high stoping width areas and the research team would make sure that preconditioning was implemented regularly and properly in these sites. It was also decided that an optimisation study would be carried out only if the monitoring of the effects of preconditioning in these research sites resulted in the conclusion that the current preconditioning technique was ineffective in high stoping width areas.
Based on the decisions made, the following process (Figure 2.1) was followed to solve this research problem.

**Figure 2.1 The process followed for the solution of this research problem**
The modifications that may be required to the preconditioning technique being used involve the positioning of the preconditioning holes and changing the length of the holes. In addition to the actual preconditioning effect, the holes may be positioned closer to the reef/hangingwall contact, in order to improve hangingwall conditions. The other possibility is to drill longer (e.g. 3.6 m) preconditioning holes by using longer (e.g. 3.8 m) drill-steels.

The effectiveness of these modifications to the preconditioning design would be quantified by making use of proven assessment tools (fracture mapping, seismic monitoring, hangingwall profiling, production information, etc.).

2.4 Site investigations

In April 2001, two well-monitored preconditioning experiments were planned in high stoping width areas. Two underground sites, a VCR stope (94/44) at Mponeng Gold Mine and a Carbon Leader stope at 5 East Shaft of Driefontein Gold Mine, were identified. Mponeng mine has already been mining some VCR at high stoping widths and Driefontein Gold Mine was the only mine that had wide Carbon leader reserves and was planning to mine these reserves in the near future. Site investigation activities at 94/44 VCR stope at Mponeng Gold Mine were immediately initiated. However, there was no mining at high stoping widths available at 5 East Shaft of Driefontein Gold Mine at that time as this mine was still developing raises in their wide Carbon Leader (C/L) reef area.

2.4.1 Mponeng Gold Mine 94/44 VCR stope

Initial visits made to the VCR stope (94/44) at Mponeng Gold Mine where preconditioning was being used, revealed problems in the implementation and indicated some modifications which needed to be made to facilitate effective implementation. The stope crew’s knowledge of preconditioning was found to be very limited. Therefore, as was recommended in the final report of the GAP336 project, the production personnel at all levels were called up for education and training on surface. An interactive training seminar was held for the top and middle management group and separate training sessions were carried out for the stoping crew, including the miner.

However, before the initiation of actual implementation of preconditioning at the 94/44 VCR stope, the miner in charge was injured due to a faceburst and subsequently was replaced by another miner who had no knowledge of preconditioning. After he went through a separate training and education programme, the preconditioning was initiated
in one panel (East 7). However, two weeks after the initiation of preconditioning, the new miner terminated his employment at the mine. Following the training of another new miner, preconditioning was re-initiated in another panel (East 5). Unfortunately this attempt did not last long and the mine management decided to stop mining activities at 94/44 VCR stope by the middle of September 2001, due to a very low grade. Owing to this decision, the project activities at this site had to be terminated. Subsequently, the project team, together with mine rock mechanics officials, identified a new site at the mine, namely 109/48 VCR stope (Figure 2.2), which was one of the deepest VCR stopes in the mine.

Despite the fact that the research activities were undermined by numerous production related problems, preconditioning was successfully implemented at the 94/44 VCR stope and significant improvements in ground conditions were observed in the preconditioned panels. After the introduction of the proper preconditioning technique at this site, no faceburst incidence was reported. Although some major problems on the timing of preconditioning blastholes were experienced at the initial stages of implementation, these were corrected through intense training and coaching.

2.4.2 Mponeng Gold Mine 109/48 VCR stope

Following the termination of the research activities at 94/44 VCR stope, a new site at the mine, namely 109/48 VCR stope, was identified. After a proper education and training programme, preconditioning was initiated in four panels (E1, E2, E3 and E4) shown in Figure 2.2.

Since the introduction of the proper preconditioning technique at this site, no faceburst incidence was reported. Similar to 94/44 VCR stope, some problems on the timing of preconditioning blastholes were experienced at the initial stages of implementation but these have been corrected through training and coaching.

Improved hangingwall conditions were observed where preconditioning holes were drilled at about 60 cm below the reef/hangingwall contact (Figure 2.3). Conversely, overhanging hangingwall conditions were observed where the preconditioning holes were drilled more than 1 m from the reef/hangingwall contact (Figure 2.4). Improved face advance per blast was also reported by production personnel after the implementation of preconditioning.
Towards the end of November 2001, Mponeng Mine management decided to stop the mining activity at E1 and E2 panels temporarily and to move the mining crew to W1 panel (Figure 2.2).

Due to a temporary stoppage at 109/48 stope, a new site (109/51 VCR stope) was identified and the mining crew started implementing preconditioning after training was provided by the project team.

The E1 and E2 panels at 109/48 VCR stope were back in production in late January 2002 and the monitoring of preconditioning at this site was resumed. After this date the project activities were carried out at both sites (109/48 stope and 109/51 VCR stope) at Mponeng Gold Mine.

The underground site at 109/48 VCR stope at Mponeng Gold Mine was instrumented with ground motion monitors in February 2002. The results of data acquisition are presented in Section 3.
2.4.3 Mponeng Gold Mine 109/51 VCR stope

During a temporary stoppage at 109/48 stope, 109/51 VCR stope was identified as a potential research site. Following a site visit it was decided that the preconditioning research activities should be continued at this stope. The mining crew started implementing preconditioning after a proper training was provided by the project team.

Preconditioning was successfully implemented at the 109/51 VCR stope and significant improvements in ground control were observed in the preconditioned panels. Since the introduction of preconditioning at this site, no faceburst incidents were reported. Improved hangingwall conditions were observed where preconditioning holes were drilled at about 60 cm below the reef/hangingwall contact. Improved face advance per blast was also reported by production personnel. Conversely, overhanging hangingwall conditions were observed where the preconditioning holes were drilled more than 1 m from the reef/hangingwall contact.
Further analyses of Ground Motion Monitoring data obtained from this site have provided better insight about how stress transfer is achieved by preconditioning (see Section 3).
Figure 2.5  Improved hangingwall conditions where the preconditioning hole was drilled at about 60 cm below the reef / hangingwall contact

2.5 Other implementation sites

2.5.1 Kloof Gold Mine, 7 shaft

One panel crew at Kloof Gold Mine 7 shaft (ex-Leeudoorn) was previously educated and trained for implementing preconditioning. The training was continued underground to show the correct marking, drilling, charging-up and tying-up procedures. The implementation site was an updip panel in the VCR that was being mined towards the old workings to get access for water and air services. The area was seismically active. The mine rock mechanics department was concerned about the level of seismic activity and the possibility of face bursting in this panel. Initially the drill-machine operators were reluctant to drill long preconditioning holes and did not believe that preconditioning would improve mining conditions and provide a safer working environment. After the initiation of preconditioning, the seismic activity was shifted to off-shift hours following the preconditioning blast and no faceburst incidence was reported. After observing the
improvement in the ground conditions, the stope crew was convinced about the positive effects of preconditioning. This implementation at Kloof Gold Mine 7 shaft was completed without a problem and the panel safely holed through to the old workings with the aid of preconditioning.

*Figure 2.6 Overhanging hangingwall conditions where the preconditioning hole was drilled at a distance greater than 1 m below the reef / hangingwall contact*
2.5.2 Driefontein Gold Mine, 4 East shaft

TRAISC, a training consultant company, was contracted by the mine to carry out the education and training of a stope crew to implement mining with preconditioning. Since TRAISC did not have the expertise to train the stope crew underground, they contacted the Miningtek’s preconditioning research team to assist the implementation of preconditioning in this site. The research team was involved in training the stope crew underground by showing the correct application of preconditioning on two consecutive days. Owing to the very short involvement in this implementation case, it is not possible to state whether any improvement was observed after the implementation or whether the stope crew continued to apply preconditioning properly and regularly.

2.5.3 Tau Tona Gold Mine

A proper training and education programme was also run at Tau Tona Gold Mine. Education seminars were held for four stope crews over a period of two days. Various critical issues concerning the implementation of preconditioning were discussed. Initially, the production personnel at all levels were very enthusiastic about preconditioning.

The implementation site was in a shaft pillar area mining the Carbon Leader reef. Subsequent to surface seminars, it was reported that the production personnel started to implement preconditioning at this site. During the first visit to this site, it was observed that the production round length was only 0.5 m and the length of the preconditioning holes was 1.5 m. When the production personnel were asked about the reasons behind the drilling of short preconditioning holes, it was realised that they had assumed incorrectly that the length of the preconditioning holes should be three times the production round length. They were reminded that the required length of the preconditioning holes is not dependent on the production round length and must be a minimum of 2.1 m. Since the standard backfill to face distance is very small at this stope, drilling of long (2.1 m or longer) preconditioning holes was not possible with long (single length) drill-steels. It was recommended that the long preconditioning holes should be drilled with extension rods. Long (i.e. 2.1 m) preconditioning holes were only drilled at the advance heading below the panel and significant improvements in the ground conditions were observed.

However, the misconception of drilling preconditioning holes three times longer than the production holes could not be changed and the drilling crew continued to drill 1.5 m long
preconditioning holes. Finally, the mine rock mechanics department halted this implementation attempt.

2.5.4 Driefontein Gold Mine, 1 East shaft

A few years ago, a pattern of preconditioning blast holes was provided for a development end at Kloof No. 4 shaft which was driven through a dyke and experiencing strain bursting and instability problems (Adams & Geyser, (1999)). The pattern was based on the experience gained from stope preconditioning experiments and engineering judgment. The technique was found to be successful in minimizing the strain bursting, and no injuries to personnel occurred while the development end advanced through the dyke.

A year ago, a major instability problem and associated fatal accident was experienced in one of the twin haulages at 1 East shaft of Driefontein Consolidated Gold Mine. Subsequently, the Miningtek’s preconditioning research team was involved in a project that included a change in support and implementation of preconditioning to alleviate the problem. The team’s role was to design and implement a layout for preconditioning holes as well as micro-seismic monitoring to assess the effectiveness of preconditioning and to determine the minimum re-entry time following a preconditioning blast. Despite a rockburst occurring as a result of a preconditioning blast triggering a pair of seismic events, no injuries to personnel occurred after preconditioning was implemented at this site.

2.5.5 South deep (Placer Dome) Gold Mine

An education and training seminar was held at South Deep (Placer Dome) Gold Mine and created a very enthusiastic approach towards preconditioning. Mine management decided to implement preconditioning at a few panels on a trial basis. A short training course was supplied to production personnel (i.e. stope crew) during an underground visit to a previously identified site. During this visit a sub-standard preconditioning application was observed and the production personnel reported that this technique was implemented according to the description by a site representative of an explosives company. The correct implementation procedure was described to the production personnel by the project team. Following this, a separate seminar was held with all site representatives of the explosives company. Various issues concerning the
implementation of preconditioning were discussed and misconceptions about preconditioning were addressed.

This mine later requested the research team to assist with the implementation of preconditioning in another stope. Following an education and training seminar on surface, a number of underground training sessions were held. The site was a backfilled stope with a very low rate of face advance. A high intensity of low angled (shallow dipping) fractures in the hangingwall was noted. Despite explaining the importance of drilling all preconditioning holes, follow up visits showed that some preconditioning holes were not drilled before the previous face blast. Since the middle management (i.e. shift boss and mine overseer) did not fully support the implementation of preconditioning, sub-standard application of preconditioning could not be changed and this site could not benefit from this implementation.

2.5.6 Savuka Gold Mine

Savuka Gold Mine requested the research team to help implement preconditioning in 28 VCR panels at this mine. The mine rock mechanics department, together with the research team, trained all levels of the production personnel in groups according to the recommended implementation procedure. In addition to on-the-job training, the panels were audited several times and corrective measures were taken where sub-standard preconditioning applications were observed. The mine rock mechanics department have implemented a “seismic risk rating” for all panels. Most of these panels were previously rated as very high seismic risk areas. Following the implementation of preconditioning, without exception, all the panels where preconditioning was applied properly were rated as low seismic risk areas.

Recently, a shift boss reported that he uses this rating system as a measure of the effectiveness of preconditioning in his responsible area. He reported that when he notices that one of his panels is rated as “high seismic risk area”, he audits the standard of preconditioning in that panel and manages the seismic risk by attending to the problems associated with sub-standard preconditioning applications.
3 STUDY THE TEMPORAL DISTRIBUTION AND SPATIAL MIGRATION OF SEISMICITY AFTER THE PRECONDITIONING BLASTS

3.1 Introduction

There are a number of recent studies (Malan and Spottiswoode, 1997; Malan, 1999) indicating that the change in the local stress state ahead of the face has a time dependant character. The stress peak ahead of the face is expected to move with the face advance and it is dependant on the rate of mining. It is also expected that there is a close relationship between the state of the stress and micro-seismic activity occurring ahead of the face.

In this project we investigate the temporal and spatial distribution of micro-seismic events ahead of the face to evaluate the effect of face-perpendicular preconditioning.

3.2 Analysing technique

It is currently not feasible to measure the position and magnitude of the stress peaks ahead of underground stopes due to technical difficulties and excessive cost. Therefore, indirect methods were used to validate the preconditioning model:

- investigating the temporal distribution of seismic events ahead of stope faces after the preconditioning blasts
- investigating the spatial migration of seismic events ahead of stope faces after the preconditioning blasts

3.2.1 Temporal distribution

The temporal distribution of the seismic events after the preconditioning blasts was analysed using Omori’s method for analysing foreshock and aftershock seismic sequences. The application of this method on mining seismic data was described by Spottiswoode (2001). In this approximation, the beginning of a preconditioning blasting
sequence was considered as a main shock and the following induced seismicity was modelled as an aftershock sequence.

Aftershock sequences typically follow Omori’s law (Utsu et al., 1995):

\[ n(t) = K(t + c)^{-p} \]  

where:

- \( n(t) \) = the rate of seismicity,
- \( t \) = time after the main shock,
- \( K \) = a constant.
- \( c \) = a small time offset and
- \( p \) = a constant

The original work by Omori used \( p = 1.0 \), but this was adopted to allow for other values. A value of \( p \approx 1.0 \) is usually found.

Software using this method was written by Spottiswoode (2002). The code reads the lists of events from an input data file and sorts a list of aftershock times for cumulative event plots. Then, aftershock times are “binned” into 4, 8, 16, 20, 24, 28, 32, 36 and 40-event bins suitable for plotting event rates as a function of time. The binning procedure is an improvement over the time bins used in Spottiswoode (2000).

### 3.2.2 Spatial migration

The spatial distribution of the seismic events can be analysed with respect to the spatial migration of the seismic events forward from the face after the preconditioning blast. The time difference between the blast and the following seismic events was calculated to be:

\[ \Delta T = t_e - t_b \]  

where \( t_e \) the time of each of the following events and \( t_b \) is time of the reference blast

The differences in the spatial coordinates \( \Delta X, \Delta Y \) and \( \Delta Z \) were calculated using the same logic:
\[ \Delta X = x_e - x_h; \]
\[ \Delta Y = y_e - y_h; \]
\[ \Delta Z = z_e - z_h; \]

where \( x_e, y_e \) and \( z_e \) are the coordinates of each event; and \( x_h, y_h \) and \( z_h \) are coordinates of the preconditioning blast.

Furthermore, to identify the migration along the direction of mining, the event positions were calculated in terms of rotated axis \( X', Y' \) and \( Z' \) where the \( X' \) is normal to the face and \( Y' \) is parallel to the face.

\[
\begin{bmatrix}
X' \\
Y' \\
Z'
\end{bmatrix} = \begin{bmatrix}
\cos\theta & -\sin\theta & 0 \\
\sin\theta & \cos\theta & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

Equation (4) enables the migration of seismic events following the preconditioning blasts to be plotted along the direction of mining.

### 3.3 Site descriptions and results

#### 3.3.1 Site 109/48 VCR stope at Mponeng Gold Mine

The underground site at the 109/48 VCR stope at Mponeng Gold Mine was instrumented with a ground motion monitor (GMM) assembled with 5 uniaxial geophones and one triaxial geophone. The recording configuration was chosen in such a way as to ensure coverage in the panels where the preconditioning took place. A schematic illustration of this recording configuration is shown in Figure 3.1.

The site was monitored for a period of three months, from March 2002 until May 2002. During the monitoring period 884 seismic events were recorded. This number includes the preconditioning blasting sequences, the mining induced seismic events and the production blasts from the neighbouring mining.
All waveforms were visually inspected to separate the blasting events from the near- and far-field seismic events. The information obtained from the seismograms was compared to the information recorded from the mine blasting survey. A summary of the preconditioning blasts performed during the monitoring period is given in the Table 3.1.

3.3.2 Temporal distribution of the seismic events at site 109/48 VCR stope at Mponeng mine

Figure 3.2 illustrates the rate of seismic events following the preconditioning blasts in panel E1 binned into 8-events bins as a function of time.

A slope of $p=1$ was found for this data set indicating the consistent decay of number of events after the preconditioning.

Figure 3.1 The schematic view of the mining layout and recording configuration at 109/48 stope at Mponeng Gold Mine
All preconditioning sequences were stacked in time and the cumulative number of events is shown in Figure 3.3.

**Table 3.1 Summary of the preconditioning blasting sequences at 109/48 stope, Mponeng Gold Mine**

<table>
<thead>
<tr>
<th>Date</th>
<th>Position in respect to the face</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 March 2002</td>
<td>Face</td>
</tr>
<tr>
<td>11 March 2002</td>
<td>Face</td>
</tr>
<tr>
<td>12 March 2002</td>
<td>Face</td>
</tr>
<tr>
<td>18 March 2002</td>
<td>The gully</td>
</tr>
<tr>
<td>2 April 2002</td>
<td>The bottom portion of the panel</td>
</tr>
<tr>
<td>3 April 2002</td>
<td>The top portion of the panel</td>
</tr>
<tr>
<td>17 April 2002</td>
<td>Face</td>
</tr>
<tr>
<td>18 April 2002</td>
<td>Face</td>
</tr>
<tr>
<td>19 April 2002</td>
<td>Face</td>
</tr>
<tr>
<td>24 April 2002</td>
<td>Face</td>
</tr>
<tr>
<td>25 April 2002</td>
<td>Face</td>
</tr>
<tr>
<td>29 April 2002</td>
<td>The top portion of the panel</td>
</tr>
<tr>
<td>30 April 2002</td>
<td>The top portion of the panel</td>
</tr>
<tr>
<td>2 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>7 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>9 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>10 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>15 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>16 May 2002</td>
<td>The top portion of the panel</td>
</tr>
<tr>
<td>17 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>18 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>21 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>22 May 2002</td>
<td>The gully</td>
</tr>
<tr>
<td>24 May 2002</td>
<td>The gully</td>
</tr>
<tr>
<td>27 May 2002</td>
<td>Face</td>
</tr>
<tr>
<td>28 May 2002</td>
<td>The gully</td>
</tr>
<tr>
<td>29 May 2002</td>
<td>Face</td>
</tr>
</tbody>
</table>
Figure 3.2  Decay of the seismicity with time following the preconditioning blasts in panel E1

Figure 3.3  Cumulative number of events as a function of time for panel E1
The cumulative number of events (Figure 3.3) shows a logarithmic trend. It is also noticeable that the number of events decrease significantly up to one hour after the preconditioning blasts.

### 3.3.3 Spatial migration of the seismic events at site 109/48 VCR stope at Mponeng Gold Mine

A number of preconditioning blasting sequences were stacked after careful location using CSIR’s AURA software. The locations were then calculated with respect to the centre of the preconditioning panel at any point in time.

To estimate the movement of seismic events with respect to the face, the coordinate system was rotated until X-axes became normal to the face and the Y-axes parallel to the face. Figure 3.4 illustrates the distribution of the seismic events along the face as a function of time.

![Spatial migration along the face](image)

**Figure 3.4 Spatial migrations of the seismic events along the face**

It is clearly shown that all seismic events plotted in Figure 3.4 are unitarily spread along the face. The migration of the seismic events ahead of the face is shown in Figure 3.5.

The distribution of the seismic events is uniform up to 20 metres ahead of the face. The majority of the seismic events were located in the distance range of 4 to 15 m.
3.3.4 Site 109/51 VCR stope at Mponeng Gold Mine

The underground site at the 109/51 VCR stope at Mponeng Gold Mine was instrumented with a ground motion monitor (GMM) assembled with 5 uniaxial geophones and one triaxial geophone. A schematic illustration of this recording configuration is shown in Figure 3.6.

The site was monitored for a period of six months from September 2002 until March 2003. During the period of reporting, more than 4400 seismic events were recorded. This number includes the preconditioning blast sequences, the mining induced seismic events and the production blasts from the mining nearby.

The waveforms were inspected visually to separate the blasting events from the near- and far-field seismic events. The general picture of the waveform analyses shows that most of the blasting sequences were disturbed by distant seismic events generated by mining of other panels. The information obtained from the seismograms was compared to the information recorded from the blasting survey. Additional analyses of the waveforms around each blasting sequence were carried out to enhance the quality of identification of post-preconditioning seismicity. A summary of the preconditioning blasts performed during the monitoring period is given in the Table 3.2.
3.3.5 Temporal distribution of the seismic events at site 109/51

VCR stope at Mponeng mine

The temporal distribution of the seismic events after the preconditioning blasts was analysed. The 28-events bin was chosen for this data set as a optimal representation of the events decay after the preconditioning blasts. Figure 3.7 illustrates the rate of seismicity following the preconditioning blasts for this panel.

A slope of $p=0.8$ was found for this data set indicating the consistent decay of the number of events after the preconditioning blast. However the time of decay of the seismic events is longer then the decay time obtained at site 109/48, Figure 3.2.
All preconditioning sequences were stacked in time and cumulative number of events is shown in Figure 3.8.

### Table 3.2 Summary of the preconditioning blasting sequences at 109/51 stope, Mponeng Gold Mine

<table>
<thead>
<tr>
<th>Date</th>
<th>Date</th>
<th>Date</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 October 2002</td>
<td>12 November 2002</td>
<td>2 January 2003</td>
<td>5 March 2003</td>
</tr>
<tr>
<td>7 October 2002</td>
<td>19 November 2002</td>
<td>7 January 2003</td>
<td></td>
</tr>
</tbody>
</table>

Similar to Figure 3.3, the cumulative number of seismic events in Figure 3.8 shows a logarithmic trend. The decay time estimated from Figure 3.8 is one hour and forty minutes.

The longer decay time can be explained by the more complicated mining environment surrounding this site and the disturbances caused by mining of nearby panels.
Figure 3.7  Decay of the seismicity with time following the preconditioning blasts

Figure 3.8  Cumulative number of events as a function of time

3.3.6  Spatial migration of the seismic events at site 109/51
VCR stope at Mponeng Gold Mine

A number of preconditioning blasting sequences were stacked after careful location. The locations were then calculated with respect to the triaxial geophone located in the bottom
of the face (see Figure 3.6). The spatial migration of the events along the face is shown in Figure 3.9.

![Spatial migration along the face](image)

**Figure 3.9** *Spatial migrations of the seismic events along the face*

It is apparent from Figure 3.9 that most of the events occur near the face. The migration of the seismic events in the perpendicular direction to the face is shown in Figure 3.10.

![Spatial migration normal to the face](image)

**Figure 3.10** *Spatial migrations of the seismic events ahead to the face*
The majority of the seismic events shown in Figure 3.10 occur up to 24 metres from the face, during the first ten minutes after the preconditioning blast. It is also interesting to notice that the two last events are relatively close to the face.

### 3.3.7 Discussion

The time distribution of the number of events after preconditioning blasting time is very similar for both monitoring sites. The main difference is that the decay time for site 109/51 is longer than the decay time at site 109/48. This result can be explained by the complicated mining layout around site 109/51. This indicates that the mining geometry could affect the post-preconditioning seismic activity.

The spatial migration of the seismic events after the preconditioning blasts was maintained for both sites. Most of the seismic events are uniformly distributed up to 24 m ahead of the face within the first 10 minutes after the blast, which can be used as an indicator of the time for relaxation or transfer of stresses after the preconditioning blasts. This time was found to be faster than the relaxation times obtained after the production blasts studied by Milev (2000) on data recorded at Blyvooruitzicht Gold Mine by Lightfoot et al. (1996).

The temporal behaviour of the seismic events following the face-perpendicular preconditioning blasts, analysed in this study, was found to be similar to the temporal behaviour of the face-parallel preconditioning previously reported by Milev (2000).
4 GEOLOGICAL AND GEOTECHNICAL MAPPING

4.1 Preconditioning site at Mponeng gold mine

Detailed geological and geotechnical mapping has been carried out on the Ventersdorp Contact Reef (VCR) at the preconditioning site at Mponeng Gold Mine. The objective of this exercise was to examine the condition of the rock-mass as a result of preconditioning at a high stoping width. As all the sites visited (Figure 4.1) had been preconditioned, it was not possible to do a direct comparison of preconditioned and un-preconditioned areas of high stoping width. Instead, the discontinuity patterns are analysed in comparison to previous discontinuity mapping of narrower VCR. This earlier mapping showed that when preconditioning is being correctly employed, there should be:

1. Abundant face-parallel discontinuities within the reef.
2. Limited discontinuities extending into the footwall and hangingwall.
3. Fewer low-angle discontinuities in the hangingwall.
4. Improved hangingwall conditions.

The mapped discontinuities are plotted on a sketch diagram and a stereo-net to delineate the orientation of the discontinuity groups. This information is shown in Figure 4.2 and Figure 4.3. Reef discontinuities tend to be steeper dipping and of a more restricted strike orientation (Figure 4.3). In contrast to this, both the hangingwall and footwall discontinuities have a slightly broader range of both strike and dip. The spacing of the fractures in the hangingwall and footwall is also significantly greater than that of the reef horizon (Figure 4.4). Those discontinuities in the footwall and hangingwall that have a similar (i.e. face-parallel) orientation to the in-reef discontinuities are of a different character. Reef discontinuities tend to be extension fractures, with no sheared material visible; whereas the face-parallel footwall and hangingwall discontinuities are sheared, with abundant white-coloured gouge associated with them.

Geological mapping of the reef horizon (the VCR) and the hangingwall and footwall contacts was also carried out. Figure 4.5 is a cross-section of the reef horizon on the eastern side of the stope. The two areas indicated by ellipses on Figure 4.5 indicate positions of damage to the hangingwall. These occur as falls of ground, bounded on their
eastern and western edges by shear fractures. These shear fractures can also be detected in the footwall.

**Figure 4.1 Mapped areas at the preconditioning site at Mponeng mine**

In Panel E2, a “welded” top reef contact (TRC), marked by a dark-blue, pseudotachylite fault was detected. This bedding parallel fault is, however, discontinuous and was only detected over a 5 m long portion of the mapped area. Where it is present, the steep face-parallel discontinuities (produced as a result of the preconditioning) extended into the hangingwall. When the same area was visited two weeks later, there was no distinct
evidence of hangingwall damage in the area. In addition, the pseudotachylite fault was no longer visible at the top reef contact (TRC). It is suggested that when the reef is “welded” to the hangingwall by a pseudotachylite fault, the fractures produced by the preconditioning can penetrate into the hangingwall. This is probably because the very strong contacts along such a fault prevents shearing along the TRC during the face dilation associated with preconditioning.

Figure 4.2 Sketch-map showing the orientation of the mapped discontinuities. Note that the abundance of the closely spaced fractures is not shown, just the orientation. The frequency of the different groups of discontinuities is shown in Figure 4.4.

The results presented above indicate that there are:

1. Abundant face-parallel discontinuities within the reef (Figure 4.3 and Figure 4.4).
2. Limited discontinuities in the hangingwall and footwall (Figure 4.3 and Figure 4.4). Where discontinuities do occur in these horizons, they are generally sheared. This suggests that these represent stope-parallel shears that form 5 to 10 m ahead of the mining face beyond the influence of the preconditioning blast.
3. Steep dipping sheared discontinuities in the hangingwall, but very few low angle discontinuities.
4. Where the pseudotachylite fault does not form the top contact, shearing is evident along the top contact. Shearing is also evident on the bottom reef contact, suggesting movement of the reef material (bulking) as a result of the preconditioning.

Figure 4.3 Lower hemisphere, Schmidt-net projection of the mapped discontinuities. The position of the fractures is indicated by letters, R = reef, H = hangingwall and F = footwall. Arc indicates the orientation (great-circle) of the face

These facts indicate that preconditioning is being successfully employed in this area.

There are however areas of concern, where the hangingwall is exposed. It is suggested that this is not as a result of poor preconditioning but rather a combination of geological
and geotechnical factors. In the areas where poor hangingwall conditions are present there is a combination of large shear fractures (Figure 4.3) and a change in reef thickness (Figure 4.5). This means that the preconditioning and or blast-holes are not optimally sited within the reef and as such may further damage the hangingwall that has been weakened by the shear fracturing. It should be emphasised that these are special cases and do not represent the general conditions in the stope.

![Figure 4.4 Histogram of the discontinuity frequency of the footwall, hangingwall and reef](image)

**Figure 4.4** Histogram of the discontinuity frequency of the footwall, hangingwall and reef

![Figure 4.5 Mapping of the reef horizon on the eastern side of the stope. Ellipses indicate fall of ground areas.](image)

**Figure 4.5** Mapping of the reef horizon on the eastern side of the stope. Ellipses indicate fall of ground areas.
4.2 Preconditioning site at Savuka gold mine

In order to determine the applicability of preconditioning to a wide reef and its associated high stoping width, the rock mass conditions at the 66/39 Northside 9 panel at Savuka have been quantified. The interaction of the preconditioning with local geological features is also investigated.

The rock mass conditions in the N9 panel have been quantified through mapping of the reef, footwall and hangingwall, as well as hangingwall profiling. Figure 4.6 shows the position of the mapped sections as well as the hangingwall profiles. One hangingwall profile was taken within the Tarentaal Dyke and a second was measured on the reef plane itself. As the Ventersdorp Contact Reef (VCR) is so wide in this area, the footwall is often not exposed by mining (see Figure 4.7).

![Figure 4.6 Map showing the position of the mapped sections and hangingwall profiles](image)

Previous mapping of preconditioned stope has shown that if it is correctly employed, the following rock mass conditions should exist:

1. Abundant face-parallel discontinuities within the reef.
2. Limited discontinuities extending into the footwall and hangingwall.
3. Improved hangingwall conditions.
The fact that the mining cut is predominantly in the reef only, made conventional mapping of the rock mass unsuitable. This is because it is not possible to compare the discontinuities in the reef with those in the hangingwall and footwall. In the mined out areas the frequency of discontinuities in the hangingwall could be measured, whilst at the face the frequency within the reef was quantified (see Figure 4.8). In a few areas where the footwall was exposed (Sections D and E, Figure 4.7), it was possible to quantify the spacing of discontinuities in the footwall. The data from these areas is combined in Figure 4.9, which shows that there is an abundance of fracturing within the reef, working out to an average of 90 fractures per metre, whilst there is less than 9 fractures per metre in the hangingwall. There are about three times as many discontinuities in reef compared to the footwall.

The thickness of the hangingwall that is exposed is only a few centimetres and generally smooth and unfractured. In fact, imprints of the pebbles of the VCR are clearly visible in the stope hangingwall. Figure 4.10 shows the smooth hangingwall immediately above the fractured reef. Evidence of recent shearing, in the form of fine-grained “rock-flour” is found on the top-reef contact. This indicates differential movement of the reef.

If the condition of the hangingwall is quantified, it is possible to determine the effectiveness of preconditioning, with a smoother hangingwall being indicative of better preconditioning. Hangingwall profiles within the dyke and of the reef plane show that the hangingwall is much smoother out of the dyke (Figure 4.11). The differences in the profiles are summarised in Table 4.1, following the methodology of Grodner, 2000. Profiles of the variation of the distance of the hangingwall from a straight line are measured.
The mathematical and statistical characteristics of the resultant curve can be used to quantify differences in hangingwalls. The length, gradient and deviation from the mean are lower in the reef than in the dyke, indicating much better conditions in the reef. This data suggests that whilst preconditioning is able to improve hangingwall conditions in high stoping widths, it has less of an effect within a dyke. The rock within the dyke appeared to be quite blocky, with discontinuities cutting across the dyke, parallel to the face. This indicates that preconditioning is able to enhance discontinuities parallel to the face, reducing the potential of bursting from such a dyke.
Figure 4.9  Frequency of discontinuities

Figure 4.10  Photograph showing smooth hangingwall and intensely fractured reef
The mapping in this site has shown that:

1. There are abundant face-parallel, steep dipping discontinuities within the reef.
2. Limited discontinuities within the footwall and especially within the hangingwall.
3. Hangingwall conditions are good within the reef plane.

All of these facts suggest that preconditioning is working effectively at high stoping widths. In addition, there is some indication that preconditioning does improve the rock mass conditions within a dyke, by increasing the number of face-parallel discontinuities.

### 4.3 Preconditioning site at Driefontein gold mine

Detailed mapping of the geological and geotechnical characteristics of the Carbon Leader Reef and its hangingwall and footwall were carried out at 46 Level 24 – 2E, prior to the initiation of preconditioning. This report details the characteristics of the reef, without preconditioning. It was anticipated that preconditioning would commence at this wide reef Carbon Leader stope and thus the conditions before and after implementation could be defined.
The orientation, spacing and position of the various groups of discontinuities present at the site were measured. Figure 4.12 and Figure 4.13 show the general orientation of the discontinuity groups and the character of the reef. Table 4.2 is a summary of the discontinuity characteristics based on the framework indicated in Figure 4.12 and Figure 4.13. Discontinuities are described as faults if there is visible displacement along them. Indicators of displacement can include infill such as vein quartz or slickensides indicating the direction of shear. Discontinuities without displacement are termed joints.

Figure 4.12 Map showing the orientation of the discontinuities and profile positions
Figure 4.13 Reef profiles indicating the various rock types present and the numbering used to describe the discontinuity positions

Table 4.2 Discontinuity characteristics

<table>
<thead>
<tr>
<th>Station</th>
<th>Orientation</th>
<th>Frequency</th>
<th>Type</th>
<th>Position</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strike</td>
<td>Dip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>085</td>
<td>60</td>
<td>23 per 25 cm</td>
<td>Joint</td>
<td>1, 3, 4</td>
</tr>
<tr>
<td></td>
<td>095</td>
<td>65</td>
<td>30 per 25 cm</td>
<td>Joint</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>095</td>
<td>65</td>
<td>20 per 25 cm</td>
<td>Joint</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>025</td>
<td>70</td>
<td>0.4 m apart</td>
<td>Fault</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>028</td>
<td>62</td>
<td>0.8 m apart</td>
<td>Fault (vein quartz)</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>C</td>
<td>085</td>
<td>60</td>
<td>20 per 25 cm</td>
<td>Joint</td>
<td>1, 3</td>
</tr>
<tr>
<td></td>
<td>095</td>
<td>65</td>
<td>27 per 25 cm</td>
<td>Joint</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>095</td>
<td>65</td>
<td>30 per 25 cm</td>
<td>Joint</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>035</td>
<td>66</td>
<td>1.0 m apart</td>
<td>Fault (vein quartz)</td>
<td>1, 2, 3, 4</td>
</tr>
</tbody>
</table>
From Table 4.2 it can be seen that there are three groups of discontinuities. Groups F1 and F2 are not expected to be affected by preconditioning as they represent pre-existing geological discontinuities. Group J1 joints (a and b) are expected to be altered by preconditioning, as they are most likely a result of mining induced stresses. Note that J1a has a lower frequency than J1b, despite having a very similar orientation. This is most likely due to the strengths of the different rock types (see Figure 4.13).

If the condition of the hangingwall is quantified, it is possible to determine the effectiveness of preconditioning, with a smoother hangingwall being indicative of better preconditioning. To quantify the hangingwall conditions in the stope, a hangingwall profile was measured (Grodner, 2000). Profiles are determined by measuring the distance of the hangingwall from a straight base line. The mathematical and statistical characteristics of the resultant curve (Table 4.3) can be used to quantify differences in hangingwalls (see Grodner, 2000). The profile is shown in Figure 4.14. This data was planned to be used to compare the changes (if any) in rock mass conditions after the introduction of preconditioning but this comparison was not carried out because of the problems associated with the implementation of preconditioning at this site.

![Figure 4.14 Hangingwall profile (see Figure 4.12 for position and orientation – the y-axis scale is in millimetres and the x-axis scale is in centimetres)](image)

**Table 4.3  Characteristics of the hangingwall profile measured**

<table>
<thead>
<tr>
<th>Length of profile*</th>
<th>Gradient of profile*</th>
<th>Deviation of profile from mean*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2194</td>
<td>2.3</td>
<td>116</td>
</tr>
</tbody>
</table>

*See Grodner, M., 2000.

The rock mass and geological conditions in a wide-reef Carbon Leader stope are quantified, to allow comparison with the rock mass after the introduction of preconditioning. The area mapped shows a large number of discontinuities in the reef and the hangingwall and footwall. These discontinuities are formed as a result of mining induced stresses. This is especially prevalent in the more siliceous rocks at the site. It is
anticipated that preconditioning will alter the frequency of occurrence of the discontinuities, reducing their frequency in the hangingwall and footwall and enhancing the frequency within the reef. This would result in an improvement in ground conditions.

4.4 Unpreconditioned site at Savuka gold mine

The W1 panel of 70/31 at Savuka Mine was geologically and geotechnically mapped. These results are presented in the Figure 4.15 below. Although this area was not mined at high stoping width and was not preconditioned, it did highlight the problems that could be alleviated by preconditioning. These include:

1. Extensive falls of ground (FOG) and poor hangingwall conditions.
2. Numerous seismic events. Several small seismic events were heard during the mapping. Evidence of seismic damage to the face at Section D was apparent.
3. Excessive damage to the footwall and hangingwall during these seismic events.

![Figure 4.15 Summary of mapping results](image)
It is suggested that even though the FOGs terminate on calcite jointing in the hangingwall, these are caused by mining induced fractures extending up to this reef-parallel joint surface. Preconditioning would reduce the extent of mining induced fractures in the hangingwall.

### 4.5 Summary

Mapping of the high stoping width preconditioning sites has shown that preconditioning can be effectively used at higher stoping widths. Evidences for this include:

1. The presence of abundant face-parallel discontinuities within the reef.
2. Limited discontinuities within the hanging- and footwall.
3. Smoother hangingwall conditions with fewer low angle discontinuities.
4. Evidence of dilation of the reef along the top reef contact.

In addition this work has shown that preconditioning improves rock mass conditions when a potentially dangerous feature such as a dyke is encountered during stoping operations. These improvements include an increase in the number of face-parallel discontinuities (which act as a barrier to absorb the seismic energy of a rockburst and thus reduce the potential of face bursting) and the shearing along the fractures in the stope hangingwall, resulting in fewer discontinuities penetrating into the hangingwall. This reduces the potential for fall of grounds and reduces dilution.
5 IMPLEMENTATION OF PRECONDITIONING

5.1 Introduction

When more recent findings and the current understanding of preconditioning were communicated to the mining industry via a number of seminars, a considerable amount of interest and a positive attitude were shown in response. Consequently, several mines have started preconditioning under various mining conditions. The project team has been approached on several occasions by individual mines for advice concerning the technique and its applicability to their particular situation and to provide some input to ensure that preconditioning is being implemented appropriately.

In order to comply with the requirements of technology transfer task of this research project, in parallel to the research activities in identified sites, the project team was also involved in implementation of preconditioning at various other stopes in different mines (Section 2.5). In addition to greater experience of various aspects of implementation of preconditioning gained, these experiments were very valuable in terms of identifying the shortcomings in previously recommended implementation procedure. The training needs of the underground personnel responsible for the correct implementation of preconditioning were also determined.

Several issues, including both concerns and supportive comments, related to the implementation of preconditioning were raised and discussed during the interactions with various parties in South African mining industry. In addition to these, a number of misconceptions were identified.

5.2 Problems associated with the implementation of preconditioning

There is general lack of understanding of why there is a need for preconditioning and which problems are addressed by implementing this technique. In addition, it was found that “how the technique works” is not fully understood. If these are not known by all the relevant personnel at the mine, any attempt to implement preconditioning will be very difficult and the likelihood of failure of the implementation will greatly be increased.
The proper education and training have great importance in the correct application of the technique. The key issues for the successful implementation of the preconditioning are “how to implement the technique correctly” and “why correct implementation is necessary”. If these are not addressed properly during the education and training programme, the consequence will be poor application of preconditioning and failure.

Historically, there is a resistance to new methods and techniques at some levels in the mining industry. The attitude of some mining people appears to be “I've been doing this work for many years, why do I need to change now”. It is almost a second nature for human beings, that once a routine job is carried out for some time, a “tunnel vision” behaviour is formed. It is very difficult to deviate from the routine. This is one of the major hurdles while trying to implement new techniques. This attitude has to be overcome by the acceptance of the benefits of the new technique by the people who will apply it. This can be achieved by educating, training and discussing the case examples and benefits of the new technique.

Continued interest has paramount importance in the implementation of any new technique. The interest should be emphasized by back-up and follow-up by the mine management. Recognition of successful applications will also be a driving force for the new techniques.

Production personnel must be committed to implement the new technique. This can be achieved if the new technique has the buy-in of the production personnel. A new technique will remain a “good idea amongst many” if it is not brought to life. Personnel implementing the technique must believe in the benefits that they will get out of it and must have ownership and the pride of success.

Mine’s rock engineering personnel must familiarise themselves with the technical aspects of the technique. Once this is mastered, continuous monitoring and regular audits need to be conducted by trained rock engineering personnel. Assessment of the effectiveness of the technique must be reported back to management and to the personnel who are responsible for the implementation of the technique. Reports should include any significant changes to the working environment (i.e. hangingwall conditions, seismic damage, etc.) as well as identified shortcomings and recommendations to solve problems.

The decision on where and when to implement preconditioning in a particular stope must be made by the rock engineering department. On the other hand, the production
personnel's approach towards preconditioning is one of the most important factors in determining the success of preconditioning. This became apparent at the early stages of the SIMRAC research project (GAP336) and has been confirmed on a number of occasions subsequently. This issue was addressed in the recommended implementation procedure. It was strongly stated that the concept must be sold to the production personnel during education and training programmes. Without production personnel's buy-in and commitment the success and continuity of preconditioning is almost impossible.

During the educational seminars prior to the implementation of preconditioning and the interactions (e.g. underground training, interviews), it became apparent that the lower categories of production personnel have very limited knowledge of rock engineering and therefore have little background from which they can appreciate concepts such as preconditioning. This makes it extremely difficult to explain to them "how and why facebursts occur", "why do they need to apply preconditioning" and "how does preconditioning work to minimise the potential for facebursts and the damage caused by them". This is of concern because, with production personnel not fully understanding the concept of preconditioning and the importance of carrying out certain procedures properly and consistently, it is almost impossible to achieve successful implementation. Rock engineering personnel should assist in the training of production personnel on basic concepts and how to recognize the effect of properly implemented preconditioning.

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

There is a great danger in getting recommendations from parties not experienced with preconditioning. The consequences of incorrectly implemented preconditioning can be to worsen conditions. It is better not to implement the technique than to implement it with inadequate knowledge and experience.

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

In every aspect of the implementation of a new technique the success depends hugely on the existence of a dedicated champion who will take the ownership. This is also true for preconditioning. If one person at the mine champions preconditioning, the success of the technique is more likely. It is important that this champion should keep close relations with the other industry champions and researchers so that he/she can communicate new information related to preconditioning. Absence of the champion will impact negatively, individuals will create any excuse not to pursue the technique and there will not be a person to consult with when they run into problems.

If some of the production personnel are replaced with new ones the knowledge of preconditioning will be lost. It will take some time for the new members to adapt to the environment and the technique. This must be addressed by providing the necessary training to the new members of the team.

Many stope workers complained about the absence of the right equipment and material (e.g. drill-steels, bits, fuses, stemming material, explosives, etc.) for drilling and charging of the preconditioning holes. This problem was also experienced by the research team during several underground trials.

Due to the unavailability of 3.2 m long drill-steels, the majority of past and current preconditioning applications was carried out by using 2.4 m drill-steels which can effectively drill 2.1 m long holes. Research has shown that the effectiveness of preconditioning was significantly reduced when preconditioning holes were drilled only 2.1 m long instead of the recommended 3.0 m. Efforts must be made to ensure that 3.0 m long preconditioning holes are drilled.

Some drilling operators complained about the weight of 3.2 m long drill-steels and the difficulty of operating stope drill machines with these long drill-steels. Their argument is that the stope drill machines are not powerful enough and/or are not designed for operating with long drill-steels. It was also questioned whether the drilling machines used in the development ends can be utilised in the stope. Since many other drilling operators have no major problem of drilling long preconditioning holes with stope drill machines, the above argument is thought to be site specific and related to the compressed air pressure at the stope.
Some of the drill operators stated that they were only given a limited number of drill bits and that they are expected to use the same drill bit for drilling both production and preconditioning holes by knocking-off the bit from the short production drill-steels and placing it on the longer drill-steel. In this case they first drill the production holes and leave the drilling of preconditioning holes to the end of the shift or they tend not to drill the preconditioning holes at all.

Most of the gold mines have changed their blasting system from igniter cord and fuse to electric or non-electric detonation systems. However, some mines are still using old igniter cord fuse system. In those mines, production holes are normally charged with 1.2 m long fuses, but the preconditioning holes require 2.1 m long fuses. In order to achieve successful timing of preconditioning, it is recommended that all production holes should be charged with 2.1 m long fuses, too. Due to the unavailability of these long fuses, sometimes all production and preconditioning holes were charged with short fuses. This normally doesn’t lead to a misfire but a very ineffective preconditioning blast since the stemming column of the preconditioning hole is removed by the production blast around it. As a result of this, conical shape blow-outs can be observed at the positions of the preconditioning holes at the face, following the blast.

Some production personnel whose duty is the charging up of the blast holes ignore the importance of stemming on the blast efficiency. Many preconditioning holes were blasted with no stemming or very short stemming and this fact was only realised on the following day during the research team's assessment of the efficiency of the previous day's preconditioning. The condition of the sockets from the previous day's preconditioning holes is a very good indicator of the effectiveness of preconditioning. The presence of a highly fractured (i.e. crushed) zone around a preconditioning blast hole and a difficulty in observing clearly defined sockets are the indicators of a good preconditioning blast. On the other hand, an almost intact preconditioning blast hole socket is an indicator of either a poor stemming or wrong timing of the blast round.

Since the production holes are normally drilled 1.1 m long, 1.5 m long charging sticks are sufficient to load explosive cartridges. In order to charge a 3 m long preconditioning hole properly, 3.5 m long charging sticks are required. If these long charging sticks are not available in the stope, production personnel use short charging sticks to load explosive cartridges into the preconditioning holes. This results in insufficient charging of preconditioning holes and therefore a less effective preconditioning blast.
Low-pressure compressed air supply was reported by some members of the drilling team and argued as one of the reasons for not being able to drill long preconditioning holes. Low-pressure compressed air supply is mainly due to leakages in the supply column amongst a number of other reasons and results in extended time spent on drilling conventional production holes and limited time available to complete the drilling of preconditioning holes in one shift. Under these conditions some drilling teams then give priority to completing the production round without drilling the preconditioning holes. Some drill operators stated that the compressed air pressure is sufficient to drill shorter production holes but not sufficient to drill the preconditioning holes. The real problem could be that some stope drill machines are unable to operate with long drill-steels. This whole argument was not supported by other production personnel in a supervisory role (e.g. Shift Bosses and Mine Overseers). This problem may be site specific or groundless as many other drilling crews have no problem drilling long preconditioning holes.

Some production personnel complained that the cleaning of the panel was not completed by the night shift crew and the day shift crew had to do the remaining cleaning work. Therefore, the machine operators could only start drilling late in the shift. When this happens, they tend not to drill the preconditioning holes but only the production holes.

During interviews, the machine operators also stated that the drilling of preconditioning holes is extra work for them and they believe they must be paid extra for doing it. Although the implementation of preconditioning is an extra work for drilling crew, the benefits of preconditioning (e.g. much safer and easier working environment and the increased productivity) may outweigh the necessity for additional payments.

Due to the increased pressure on the production personnel closer to the monthly measurement day, they tend to give lower priority to preconditioning at this time and this results in sub-standard or no preconditioning at all. This normally happens during the early stages of the introduction of preconditioning at a particular stope before it becomes apparent to production personnel that properly executed preconditioning increases productivity (i.e. face advance per blast). In fact, over and above the effects of improving safety, the positive effect of preconditioning on productivity (Toper et. al. 1998) is the major benefit apparent to the production personnel and the major motivation for others to apply it.

The preconditioning research team has studied the effects of blast parameters on the efficiency of preconditioning during the optimisation of the technique. Although minimal differences were observed in the effectiveness of preconditioning by varying the hole
lengths between 2.4 m and 3.6 m and the hole diameters between 36 mm and 40 mm, it was concluded that, preconditioning holes must be drilled 3 m long and at the same diameter as production holes. These recommended blast parameters for preconditioning were communicated to the industry by means of publishing guidelines for proper implementation of preconditioning and during education and training seminars. However, there still seems to be a lack of knowledge and understanding of correct procedures or confusion and disregard of the recommended blast parameters for efficient preconditioning.

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

Very early research work involving the monitoring of the blast efficiencies in a remote development end had shown that more gaseous explosives were expected to perform better in preconditioning blasts. However, no major difference in blast efficiency was observed during the monitoring of the actual preconditioning blasts by using different types of explosives at research sites. For ease of implementation, it is recommended that the same explosive type be used for both the preconditioning and the production blast holes.

The problems associated with charging-up and stemming of preconditioning holes were caused mainly by the unavailability of the right equipment (e.g. charging stick) and material (e.g. stemming material), which was discussed in earlier sections. It must be
restated that improper charging and stemming of a preconditioning blast hole is responsible mainly for the reduction in the blast efficiency and may result in ineffective preconditioning.

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

The major motivation for production personnel to implement preconditioning is the safety and the significant improvement of productivity and hangingwall conditions (Toper et. al. 1998). This effect is proven by research projects and confirmed by almost every proper implementation of the technique. Some production personnel are happy to implement preconditioning at every stope regardless of whether a faceburst problem exists. However, some rock engineering personnel are reluctant to go this route and argue that the preconditioning must only be applied at stopes where there is a potential faceburst problem.

Although the mechanism of preconditioning was explained in detail in research reports, even some rock engineering personnel still do not completely understand the concept. The major point of argument is whether preconditioning destresses the ground by further fracturing it or remobilising and extending the existing fractures. Mapping and comparing thousands of fractures in the hangingwall before and after preconditioning have shown that correctly designed preconditioning does not create any significant additional fracturing in the hangingwall. On the other hand, when a panel is inspected following a preconditioning blast, a highly fractured (crushed) zone around preconditioning hole sockets and a few radial blast induced fractures are observed. It is also noted that all the blast induced fractures terminate either at some distance from, or exactly at, the hangingwall/reef contact. Since the preconditioning holes are placed in already fractured ground, most of the blast energy is attenuated through the remobilisation of existing fractures. In conclusion, the main mechanism of preconditioning is through the remobilisation and extension of these existing fractures.

The incorrect timing and/or ineffective stemming causes conical shape blow-outs at the positions of the preconditioning holes after the face is blasted. Some production
personnel consider these blow-outs as a sign of good preconditioning. In fact, it is an indication of incorrect timing and/or ineffective stemming.

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

Many attempts at initiating the implementation of preconditioning have failed and have been terminated at very early stages of application (e.g. within two weeks after the initiation). Most of these did not make use of the recommended implementation procedure and employed a sub-standard technique. Most interestingly, the mine personnel blamed the preconditioning technique itself rather than recognizing the influence of the improper implementation on the poor results obtained. Discussions of these bad experiences have unfortunately caused misconceptions and bad publicity for preconditioning in sections of the mining industry.
6 GUIDELINES FOR THE IMPLEMENTATION OF PRECONDITIONING

The SIMRAC research project (GAP336) on preconditioning was completed in December 1997 and detailed guidelines for effective and efficient implementation of preconditioning were published as part of the final project report in January 1998. During the execution of SIMRAC research project (GAP336) and following the completion of the project, the findings were communicated to the mining industry via a number of seminars. Considerable amount of interest was shown in response and consequently, several mines started implementing preconditioning in various mining environments.

During this research project (GAP811), the project team has gained further experience in implementation of preconditioning at research sites as well as the other implementation cases. This involvement enabled the authors to study the insights of these cases and to identify major shortcomings in the implementation of preconditioning. Based on these findings (Section 2.4, 2.5 and 5.2) the importance of and the need for a properly formulated education and training programme have become more apparent and the recommended implementation procedure was updated.

6.1 A structured implementation process

6.1.1 Preliminary evaluation

Identifying the necessity for preconditioning and potential benefits is the first and one of the most important steps to be taken before planning any other phases of the implementation. The rock engineering personnel together with the senior production personnel, with or without the research team, have to investigate the applicability of preconditioning in the identified workplace. If it is thought that the research 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 state clearly the problem itself and the causes and possible solutions to the problem. Even if there is no faceburst 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.

6.1.2 Planning of the implementation programme

The same team (i.e. the rock engineering personnel together with the senior production personnel, with or without the research 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 following guidelines can be used:

The role of the rock engineering department 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 stope and must provide daily status reports to the rock mechanics department.

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

6.1.3 Education and training seminars/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 work-load 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 with the involvements in a number of implementation cases. This training scheme is focused on all relevant personnel, namely management, rock engineering department, training department, safety department and all levels of the production personnel. Instruction is conducted both on surface and underground. Mine training department 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 (Toper et. al. 1998). It is important (at the outset) to dispel 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 be easily covered by the overall gain in profits resulting from increased productivity. This overall economic benefit was carefully quantified and documented in the final report of SIMRAC project GAP030 (Lightfoot et. al. 1996).

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

- Introduction.
  - The faceburst problem: what it is, how it arises, what the effects might be and how can it 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 the 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 stope crew or management. The stope 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 the mother tongue. The instructor should ideally also be completely familiar with the working environment to which the audience is exposed.

### 6.1.4 Risk assessment

Prior to the actual implementation of preconditioning, a proper risk assessment must be done. The inclusion of production personnel is strongly recommended as this process will re-emphasize the requirement for correct application and the potential danger if it is not implemented properly. The inspectors from the Department of Mineral and Energy (DME) will also insist on risk assessment prior to 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 B.

### 6.1.5 On the job training
An expert team must assist the production personnel during 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 will be given to all affected personnel. When training the workforce underground, it is important to be able to substantiate any claims made with respect to 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 with that spent on production drilling alone.

The importance of correct application must be re-emphasized 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 quite long as the blast optimisation and the integration of this technique into actual production cycle is relatively more difficult.

6.1.6 Follow-up and assessment of the results

An initial involvement of the expert implementation team during this phase is also recommended. This phase involves placing regular follow-up and control mechanisms to ensure the continuation of regular and correct preconditioning application and must 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 usual and proper application, the rock engineering department, with 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 GUIDELINES FOR FACE-PERPENDICULAR PRECONDITIONING

The face-perpendicular preconditioning technique was studied in research project GAP811 that resulted in updating the guidelines for this technique. For guidelines for the face-parallel preconditioning, the reader is referred to the final report of SIMRAC research project (GAP336) that was published in January 1998.

7.1 Introduction

Face-perpendicular preconditioning uses standard diameter 36 – 40 mm blastholes drilled perpendicular to the stope face to a depth of 3 m and fired as an integral part of the production blast. To maximise the preconditioning effect, it is necessary for these holes to be drilled on the reef plane. The recommended spacing between preconditioning holes is 3 m. A schematic view of a face-perpendicular preconditioning layout is shown in Figure 7.1. Assuming that the panel face will be blasted once every day, and advanced a minimum of 1 m, this technique is based on a three-day cycle. On day one, the preconditioning holes are drilled together with the production holes and blasted (Figure 7.1 (a)). On the second day, once the face has been cleaned and prepared for the drilling of the next round, the drilling of new preconditioning holes commences. For this round, the preconditioning holes are offset from the preconditioning holes drilled on the previous day by about 50 cm (Figure 7.1 (b)). The preconditioning holes that are drilled on the third day are also offset from the sockets of the preconditioning holes that are drilled on the previous day by about 50 cm (Figure 7.1 (c)). By using this system, the panel face is advanced at least 3 m during these three blast cycles. Thus, the preconditioning holes on the fourth day are drilled in the same positions as on the first day (Figure 7.1 (d)), as the face has advanced beyond the ends of those holes. Sidings are just as susceptible to bursting as is the face and, therefore, these areas must also be preconditioned, as illustrated in Figure 7.1.

The recommended layouts of face-perpendicular preconditioning holes for various mining configurations (e.g. updip, underhand and overhand mining) are shown in Figure 7.2. Previous research showed that the maximum spacing between the preconditioning holes should not be more than 4 m. It is recommended that a 3 m spacing should be used.
Figure 7.1 Diagrams showing the face-perpendicular preconditioning layout for a three-day cycle

The preconditioning holes should be drilled at right angles to the face, parallel to hangingwall plane and at about 60 cm below the intended hangingwall plane, in order to reduce the chance that a hole drilled as part of the normal production round will intersect a preconditioning hole. Figure 7.3 illustrates the relative positions of the preconditioning and production holes. The closest point between the production and the preconditioning holes is at the collar and, when properly drilled, the production holes are drilled away from the preconditioning holes.
7.2 Drilling preconditioning holes

The diameter of the preconditioning holes should be of the order of 36 – 40 mm and the length should be 3 m. This allows utilisation of the drilling machines and drill-steels currently available on most mines. There is, therefore, no need to purchase special equipment. If the support is too dense or too close to the face to accommodate such long
drill-steels (as this might be the case when using backfill), extension steels might be required. These are often heavier than single drill-steels and therefore require sufficient compressed air pressure to ensure an adequate penetration rate. It is recommended that the holes be drilled using hand-held percussion drill machines with air-legs (Figure 7.4). Knock-off bits are recommended as they eliminate the need to remove the drill-steels for sharpening at the end of the shift.

Figure 7.3 Cross-section ahead of the stope face, illustrating the relative positions of the production and preconditioning holes

Drilling of a single 3 m long preconditioning hole takes less than 15 minutes. Assuming that two machines are used to drill a 30 m face, this suggests that each drilling crew would require about one and a quarter hour additional work to drill five preconditioning holes. However, in practice, it has been found that when preconditioning is ongoing, the drilling time spent per production hole can be reduced substantially. This reduction is sufficient to ensure that less total time is required to drill these extra preconditioning holes together with the production holes than is required to drill just the production holes, prior to the introduction of preconditioning at a site.

Few drilling difficulties have been reported and these have generally occurred at the start of preconditioning. When preconditioning is first introduced into a panel, the stress close to the face may be high enough to make the drilling of 3 m preconditioning holes for the
first blast problematic. The use of shorter preconditioning holes might be required initially, in order to reduce the stress at the face, and only later can a 3 m long hole be drilled without difficulty. It is recommended that if initial drilling is difficult the first two or three preconditioning blasts should be carried out using 2.2 m holes.

Success in implementing this method of preconditioning is dependent on the willingness of the drilling operators to drill these longer holes. The use of additional personnel to drill only preconditioning holes may need to be considered. However, a bonus system for additional work should be introduced only as a last resort. The use of preconditioning has been found to reduce the overall drilling times and the increased face advance rate should result in an increased production bonus. Thus, there is no real extra work involved in preconditioning drilling and a bonus is already built into the system.

7.3 Charging preconditioning holes

The purpose of preconditioning is to allow movement to take place along pre-existing fractures where blocks in the rockmass have locked up. In other words, preconditioning is aimed at eliminating the strain energy “lock-ups” due to asperities on pre-existing or
mining-induced fracturing. For this purpose, the preconditioning blast is required to provide a large quantity of gas at high pressures to open the existing fractures. It is believed that the rock in the first 3 m from the face to be preconditioned is generally in a highly fractured condition, even if some of the fractures are tightly closed by clamping forces. Therefore, a relatively low shock energy and high gas volume explosive will give a better result. ANFO is a suitable explosive as it produces a high volume of gas at a relatively low velocity of detonation. Where ANFO is not available, an emulsion explosive is a suitable alternative. Explosives must be charged in 2 m of the hole, with the remaining 1 m being stemmed as shown in Figure 7.3.

The detonation of preconditioning holes should be by top-priming the explosive charge, to facilitate removal of primers from misfired preconditioning holes (Figure 7.3). One emulsion cartridge is recommended as a primer and should be initiated with a Nonel (Figure 7.5 (b)) or electric detonator. A reliable and accurate electronic initiation system would be ideal. However, if necessary, an existing initiation system can be used, although the application of fuse/igniter cord systems is not recommended because of the difficulty of ensuring the proper firing sequence of the preconditioning holes in relation to the production holes. This system can be used as a last resort. Where only standard ignition systems are available, the tie-up configuration for an acceptable firing sequence is shown in Figure 7.5 (a). In this system, all preconditioning and production holes are charged with 2.1 m long fuses and the fuses of the preconditioning holes are connected to the igniter cord approximately 1 m in advance. This will enable the preconditioning holes to fire with a 1 m burden before the neighbouring production holes fire. Whichever initiation system is used, the common rule is “Each preconditioning hole must be initiated with a minimum of 1 m burden before the neighbouring production holes were fired”.

7.4 Stemming

As only 2 m of the preconditioning hole is charged with explosives the remaining 1 m should be tamped with a competent stemming material (Figure 7.3). Clay, bentonite, angular sand or a combination of these could be used for tamping the preconditioning holes.

Stemming is very important as an effective stemming will maximise the stemming retention time, which will contain the explosive energy in the hole as long as possible. The stemming also helps to protect the downline to the detonator and ensures that the primer cartridge remains in place while neighbouring holes are firing. Although stemming
materials other than clay have not been tested, properly tamped clay stemming seems quite effective.

Figure 7.5 Examples of the recommended tie-up configuration of (a) fuse and igniter cord or electric (b) Nonel for integrating the blasting of preconditioning and production holes
7.5 Handling of misfires and sockets

In addition to the requirement to examine the production holes for the possibility of misfires, the sockets of the preconditioning holes must also be examined after each blast. Every preconditioning hole should be identified, marked in the case of a misfire, and plugged in the case of a socket. Since the preconditioning holes are drilled perpendicular to the face and at about 60 cm below the intended hangingwal plane, their sockets can easily be identified. According to the relevant regulations no drilling can take place within 2 m of a misfire. Therefore, any misfire must be removed as soon as possible. Since each preconditioning hole is top primed, and the detonator and the primer stick lie along the breaking plane of the production holes, it should be relatively easy to clear the explosives from the misfired hole. Moreover, since preconditioning is applied with every production blast, there will be no need to re-prime and blast any misfired preconditioning hole. After the primer and remaining explosives are cleared from a misfired hole, the hole can be plugged and regarded as a socket. Current regulations state that no hole can be drilled within 15 cm of a socket. This should not be a hindrance, as the spacing between preconditioning holes and the sockets from the previous blast is not less than 50 cm.

During the trials of face-perpendicular preconditioning at the test site no preconditioning blast resulted in the misfire of a production or another preconditioning hole. Only a few misfires were experienced, these being due to igniter cord or main power line cut-off caused by seismic events before blasting took place. No difficulty in handling the misfires was reported.
8 CONCLUSIONS

The following conclusions can be drawn;

- Site investigations at experimental project sites at high stoping widths revealed that the majority of the problems were associated with the implementation of preconditioning. Owing to a fundamental lack of understanding of preconditioning, production personnel have improperly implemented preconditioning.

- When the research team ensured that preconditioning was implemented regularly and properly in these sites, after a certain period of regular and continuous preconditioning at these sites, 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 reef / hangingwall contact).

- When preconditioning holes were positioned at about 60 cm below the reef / hangingwall contact overhanging face shapes were eliminated and improved hangingwall conditions were observed and the production personnel reported that the face advance per blast was increased after the introduction of preconditioning.

- There is a clear need for an implementation team that can provide assistance with respect to the implementation of preconditioning and training of personnel on individual mines.

- The temporal distribution of the number of events after preconditioning blasting was found to be similar for both monitoring sites, 109/48 and 109/51, Mponeng mine. The only difference was the longer decay time at site 109/51 indicating that the mining layout may influence the post preconditioning seismicity.

- The spatial migration of the seismic events after the preconditioning blasts was obtained for both sites. Most of the seismic events moved up to 15 m ahead of the face. This occurred within the first 10 minutes after the blast, which can be used as an indicator of the time for relaxation or transfer of stresses after the preconditioning blasts. This time was found to be faster than the relaxation or transfer of the stresses after the production blasts reported in previous studies.
• Geological and geotechnical mapping studies of the high stoping width preconditioning sites has shown that preconditioning was effectively used at higher stoping widths. In addition, this study has also shown that preconditioning improves rockmass conditions when a potentially dangerous feature such as a dyke is encountered during stoping operations. These improvements include an increase in the number of face-parallel discontinuities in the reef (which act as a barrier to absorb the seismic energy of a rockburst and thus reduce the potential of face bursting) and the shearing along the stope hangingwall, resulting in less discontinuities penetrating into the hangingwall. This reduces the potential for fall of grounds and reduces dilution.

• Through the involvements in a number of implementation experiments the major problems associated with the implementation of preconditioning were identified. Much has been learned from this study of the latest status of preconditioning in the mining industry in terms of issues that need to be addressed in order to ensure successful future implementation of the technique. Based on the results obtained from this study the guidelines for the best implementation of preconditioning were updated and a structured implementation process was proposed.

• A booklet and a CD-based interactive training module for demonstrating the correct implementation of the preconditioning technique were produced to help the training departments of mines to continue the education and training process.

• The education of all production personnel and the training of the stope crew are essential, although these steps alone may not be sufficient for successful implementation of preconditioning. The knowledge transfer should take place both via education sessions on surface and training sessions in the workplace underground. It is important that regular follow-up should take place for a period after the initiation of preconditioning at a site. The personnel of the safety and training departments on a mine 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 production personnel prior to the introduction of preconditioning. The stope crew must be made aware not only of how to apply the
preconditioning correctly but also of the direct benefits to them in the working environment. Therefore a detailed education and training scheme has been formulated, based on 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 simply being ordered to carry it out. During the education and training of the stope crew, the direct and indirect implications in terms of their bonuses must be clearly explained as well as the safety benefits of preconditioning. Some additional incentive bonuses may be considered to ensure proper implementation of preconditioning, since it has been found to be a cost-effective safety measure (Lightfoot et. al. 1996 and Toper et. al. 1998).

- Prior to the actual implementation, a proper risk assessment procedure will re-emphasize the importance of correct application and the potential consequences of sub-standard implementation.

- The inclusion of preconditioning as part of the Code of Practice of each mine is highly recommended. This would enable the mine’s safety control personnel to follow up on compliance with the preconditioning requirement, in addition to audits being conducted by the mine’s rock engineering personnel.

- It is encouraging to see that a significant number of mines are now evaluating or implementing preconditioning to some extent. 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, particularly the mines where remnant extraction forms a significant proportion of total production.
References

AURA – Seismic software for advanced processing of mine seismic events. *Developed in CSIR Mining Technology.*


Appendix A

Education and training
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 in a system of safe mining. Sensible mine planning and adequate support design and installation continue to be important when mining with preconditioning.

The faceburst problem

Preconditioning would 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 violent failure occurs 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 stresses 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 (Lightfoot et. al 1996 and Toper et. al. 1998). Preconditioning makes use of explosives in the fractured rock ahead of mining stope faces to create a distressed 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 found that the use of preconditioning also leads to an overall improvement in ground conditions in the stope, as it tends to result in a smoother hangingwall. This has additional safety implications, as it is inherently more stable and allows for more effective support installation (Toper et. al. 1998).
The currently proposed mechanism for preconditioning has been formulated from a combination of direct underground observation and various measurements of the behaviour of the rockmass surrounding the excavation. Numerical and physical modelling of preconditioning blasting have also been used. It is thought that the re-mobilisation and extension of existing fractures leads to a reduction in the stress acting across the fractures and thereby reduces the stress levels on the face as a whole. Consequently, a buffer zone of destressed rock is created immediately ahead of the face. As the face itself is less stressed, it is less likely to burst. The transmission of seismic energy through the buffer zone from more distant, larger events is also reduced and, hence, the likelihood of damage to the stope resulting from such events.

The practical implications of the reduced face stress include more efficient drilling and more efficient blasting, in terms of both increased face advance per blast and more consistent fragmentation of the material removed by the blast. The smoother hangingwall is related to the induced shearing on the reef-hangingwall parting, which facilitates better control of the stoping width. Reduced dilution of mined ore and reduction in support requirements obviously have favourable cost implications. The combination of a safer environment and an easier workload will inevitably lead to an improvement in the morale and attitude of the workforce.

Choosing the appropriate preconditioning method

It is important to note that preconditioning should not be seen as a remedy for all rock-related problems. One should not attempt to use preconditioning to deal with an underground condition that would be more adequately improved by changing the mining method or stope layout. Preconditioning is not a substitute for good mining practice. Appropriate standards consistent with the mining environment should be used and application of those standards must be ensured.

There are two preconditioning methods, which differ in application and in effectiveness. While it is thought that the preconditioning effect produced by the face-parallel method is superior, this advantage should be weighed against the potential disruption of the mining cycle. Each method has implications in terms of face configuration, gully positioning and support design. The mining layout should facilitate the use of preconditioning, while continuing to allow for efficient removal of ore and for effective support of the rockmass surrounding the excavation.
Face-perpendicular Preconditioning

Face-perpendicular preconditioning is well suited to normal production faces, as it integrates very well into the mining cycle and so is unlikely to have a detrimental impact on production.

The preconditioning holes would typically be drilled to 3 m in length and spaced 3 m apart, although these figures would depend on local conditions. The support spacing and distance-to-face should ideally be sufficient to allow for the use of 3.2 m long drill-steels. Although concessions might be necessary in unusual circumstances (e.g. if backfill is installed very close to the face), these requirements have not been found to create major difficulties in practice and have not necessitated any compromise in the support system in the face area to date. If backfill is placed too close to the face, the extension rods can be used to drill long preconditioning holes.

The preconditioning holes would be stemmed for a distance equal to the length of the production holes but not less than 1 m, to ensure that the energy from the explosion is contained within the hole and imparted to the surrounding rockmass. The preconditioning holes are blasted as an integral part of the production blast and timed to ensure that there is at least 1 m of burden for each preconditioning hole.

Face-parallel preconditioning

Face-parallel preconditioning is recommended for use in special areas, such as remnant or pillar extraction, as it is thought to be a more effective method for dealing with the exceptional stress environments encountered in these areas. Maintaining high production from these areas is likely to be less of a concern.

It should be possible to set up the drill rig, drill the preconditioning hole, charge and blast, all within a single shift, so as to minimise any disruption to the mining cycle. For this reason, while subject to such factors as the air and water pressure at the site and the specific drilling characteristics of the rig used, it is recommended that the lengths of the individual panel faces should not exceed 20 m. The preconditioning hole should be drilled for at least the length of the panel face, although it is recommended that it be extended somewhat into the next panel.
It is obviously necessary to be able to position the large drill rig so that the preconditioning hole can be drilled (typically, 5 m ahead of the panel face). Thus, the gullies from which the drilling is to be performed should be advanced sufficiently far ahead of the face to be preconditioned. This need to accommodate the rig also impacts on the lead-lag distance between adjacent panels. A lead-lag distance of 8 m was used without significant difficulty at one of the project sites.

The stemming of face-parallel preconditioning holes is a rather more complicated issue than is the case with face-perpendicular holes. In the latter case, the stemmed length is removed with the accompanying production blast, while, in the case of face-parallel preconditioning, the rockmass in the vicinity of the stemming is not removed with the blast. The stemming needs to be sufficient to contain the explosion in the hole: the required stemming length depends on the hole length and diameter and on the degree of fracturing near the collar of the hole, but is typically about 5 m. This can result in a substantial region of effectively non-preconditioned rock adjacent to the stemmed portion of the preconditioning blast.

The preconditioning blast is initiated via two coupled detonators placed a short distance into the explosive. The preconditioning blast is manually set off and only after a successful detonation are adjacent panels to be connected for a production blast. Sequencing has a rather different interpretation here than was the case with face-perpendicular preconditioning: in the case of face-parallel preconditioning, it is important that the sequencing of adjacent panels is carefully considered. The lagging panel should always be preconditioned first, to avoid the scenario of having stress thrown back onto that panel by the preconditioning of the panel that is further ahead.

Implementing preconditioning

In this section, the instructor should deal with the practical considerations of carrying out the preconditioning in the underground environment. The positioning of the preconditioning hole(s), the size and length of hole to be drilled, the sequencing of preconditioning blasts, the charging and stemming of preconditioning holes, as well as the initiation of each preconditioning blast would all be explained in detail on surface and demonstrated in the underground environment.
Guidelines for the correct implementation

In this section the instructor will go through the detailed information on the guidelines for the correct implementation of preconditioning.

The importance of correct application

It is essential that all persons involved with the application of preconditioning should be made aware of the importance of the correct application of preconditioning, and that failure to apply the method correctly could well result in undesired effects, to the extent of worsening the situation rather than alleviating the faceburst hazard. In the case of face-perpendicular preconditioning, all of the preconditioning holes must be drilled and blasted, at the correct spacing, or 'hard' patches of stressed rock could be generated in the face, which could burst into the working areas during the subsequent shift.

In the case of face-parallel preconditioning, the preconditioning hole must be positioned within the recommended limits of distance ahead of the face. If it is placed too close to the face, damage to the face could result; if it is placed too far ahead of the face, the blast will either have no effect or it might act to transfer stress back onto the face, rather than away from it. No production blast should be taken in a panel where the face has reached the position of the previous preconditioning blast, as this would effectively be mining into non-preconditioned ground.

Assessing the effectiveness of preconditioning

While guidelines have been compiled for the application of each preconditioning method, it is important to note that the details presented in the guidelines are based on the careful, intensive study of preconditioning at only a few sites, and so should be regarded as starting points for the application of preconditioning in situations that differ markedly from those which have been investigated during the development of the technique. Thus, it is important that individual mines should monitor the effectiveness of preconditioning at their specific sites and be prepared to change some of the parameters to suit their specific conditions, so as to optimise the effectiveness of preconditioning at each site.

For face-perpendicular preconditioning, the parameters to be optimised include: hole length, hole diameter and the spacing between adjacent holes. For face-parallel preconditioning, the parameters to be optimised include: face lengths of panels, lead-lag
distances between adjacent panels, the distance ahead of the face that the preconditioning hole is placed and the diameter of the hole. In both cases, the parameters are inter-related and cannot be assessed and optimised in isolation: the goal is to optimise the preconditioning system at the site by varying the parameters so as to achieve effective preconditioning of the stope faces.

**Tools available for making the assessment**

Assessment tools which have been found to yield useful information during the development of the preconditioning technique include: underground observation, measurement of face advance and drilling rate, fragmentation assessment, fracture mapping and hangingwall profiling, closure-ride measurements and monitoring of seismicity, ground penetrating radar profiling, as well as various measures of the state of stress at the face. Clearly, some of the tools require specialist training, while others are more readily accessible to non-specialists and can be used by shift-bosses, miners and the stope crew.

Observation of underground conditions, if conducted in a discerning manner, is a simple but useful tool for assessing the effectiveness of preconditioning in a stope. 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’ (easier to bar after blasting) and the hangingwall should be smoother after preconditioning has been in use for a period. Additionally, particularly when using face-parallel preconditioning, significant bulking of the face towards the excavation should accompany a successful preconditioning blast (this will be easier to observe if paint lines are placed on the face before the blast); sophisticated photogrammetric techniques have been investigated, in an attempt to quantify the bulking effect, with limited success. Regular observation will allow for an evaluation of the continued effectiveness of preconditioning, as well.

With effective preconditioning, face advance rates should increase significantly compared with those before the introduction of preconditioning (Toper et. al. 1998). These could be measured after each blast from fixed points in the stope (e.g. support elements or closure-ride stations) and the cumulative effect should be measurable on monthly survey plans. There should also be fewer (and shorter) production hole sockets in the face after a blast when preconditioning is being used.
When drilling into preconditioned ground, drilling rates should increase significantly compared with those before the introduction of preconditioning. At one of the project sites, where face-perpendicular preconditioning was being used, it was found that the total drilling time for preconditioning and production holes was less than that required for just production drilling before the introduction of preconditioning.

The material coming off the face after a blast should be both more highly fragmented and more consistently fragmented when preconditioning is used. This has additional benefits in terms of easier cleaning of the stope face and fewer blockages of the tips and ore passes. This effect should be qualitatively discernible underground. It could be quantified by some more sophisticated means (e.g. a photographic technique), if required.

While it has been found that no new fracture sets are generated as a result of preconditioning, regular detailed fracture mapping should reveal that fractures with favourable orientations are enhanced and re-mobilised when preconditioning is used. While simple enough to be used by non-specialists, hangingwall profile measurements allow one to quantify the improvement in hangingwall conditions after the introduction of preconditioning.

Two assessment tools which have been found to have particular application in the context of face-parallel preconditioning are closure-ride measurements and the monitoring of seismicity from the site. While these tools can, in principle, be used in the assessment of face-perpendicular preconditioning as well, the size of the face-parallel preconditioning blast and its isolation from the production blast makes it particularly amenable to analysis using these tools. Closure-ride data can be acquired fairly cheaply, but the acquisition of useful seismic data obviously presupposes the installation of an adequate seismic network.

Closure-ride measurements would typically be carried out by an observer on a daily basis; various continuous closure measuring devices (e.g. clockwork closure-meter) are also available and allow one to determine the instantaneous closure at blasting time, which has been found to provide insight into the state of stress at the face. Once the site has been monitored for a while, it is possible to use the measured closure to evaluate the effectiveness of a preconditioning blast.

In the context of face-parallel preconditioning, monitoring of the seismicity from the site facilitates the evaluation of the effectiveness of a preconditioning blast in several ways. The size (magnitude, seismic moment or seismic energy release) of the recorded blast
event allows one to determine whether all of the explosive was set off successfully. Occasionally, the recorded event might be larger than expected, indicating that the blast simultaneously triggered additional strain energy release from the rockmass through an actual seismic event. Of course, it is possible for the blast to trigger a larger seismic event separated in time from the blast. In this case, two separate events would be recorded by the seismic system. Stress transfer induced by the blast would be indicated by the migration of subsequent seismicity away from the preconditioned zone. Additionally, examination of seismic source parameters should show, for example, that stress drops for seismic events in the preconditioned zone are lower than those for events in adjacent regions of the rockmass. In the case of face-perpendicular preconditioning, the effects of the preconditioning are not as obvious in the seismic data and their identification requires a very sensitive seismic network with very good location accuracy.

Although it requires special equipment and interpretation by a trained specialist, ground penetrating radar (GPR) profiling provides a very clear indication of the effects of preconditioning on the condition of the rockmass immediately ahead of the advancing stope faces. Changes in the intensity and extent of fracturing and increased separation of the fracture surfaces after a preconditioning blast should be visible in the processed GPR data. GPR scans can also be used to assess the maximum permissible separation of adjacent face-perpendicular preconditioning holes when introducing preconditioning to a new site.

In principle, direct measurement of the state of stress of the rockmass immediately ahead of the stope faces would be the ideal way to quantify the effectiveness of the preconditioning. Most of the tools commonly used for this purpose are not suited for use in fractured rock. A solid-inclusion instrument has been developed at Miningtek, but is yet to be proved for routine use. Indirect measures, such as the change in aspect ratio of rigging holes in the face, are possible indicators of the state of stress. Changes have been found in such measures after the introduction of preconditioning.
Appendix B
Example of risk assessment
## Matrix to determine Risk Index

<table>
<thead>
<tr>
<th>Index (28-48)</th>
<th>Significance</th>
<th>Priority</th>
<th>Frequency</th>
<th>More than 100 events per year</th>
<th>Between 100 and 10 events per year</th>
<th>Between 10 and 1 event per year</th>
<th>Between 1 event per year and 1 event in 10 years</th>
<th>Between 1 event in 10 years and 1 event in 100 years</th>
<th>Less than 1 event in 100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>(16-27)</td>
<td>High</td>
<td>A</td>
<td>1</td>
<td>48</td>
<td>47</td>
<td>45</td>
<td>42</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>(1-15)</td>
<td>Medium</td>
<td>B</td>
<td>2</td>
<td>46</td>
<td>44</td>
<td>41</td>
<td>37</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>C</td>
<td>3</td>
<td>43</td>
<td>40</td>
<td>36</td>
<td>31</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>39</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>34</td>
<td>29</td>
<td>24</td>
<td>19</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>28</td>
<td>23</td>
<td>18</td>
<td>13</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>22</td>
<td>17</td>
<td>12</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>16</td>
<td>11</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

- **Severity**
  - Multiple Fatalities > 6000 Shifts Lost
  - 1 Fatality ± 6000 Shifts Lost
  - 600 ~ 5999 Shifts Lost
  - 60 ~ 599 Shifts Lost
  - 6 ~ 59 Shifts Lost
  - 1 ~ 5 Shifts Lost
  - No Time Loss
  - "Near" Miss
## Preconditioning - Risk Analysis Tables

<table>
<thead>
<tr>
<th>Step</th>
<th>Hazard</th>
<th>Cause</th>
<th>Consequence</th>
<th>Existing Controls</th>
<th>Risk Index</th>
<th>Recommended Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mark the hole</td>
<td>1a) The preconditioning hole is marked too close to a socket.</td>
<td>Human factor, as the correct marking procedures/standards are not adhered to. Lack of training.</td>
<td>Personal injury if the rock drill operator drills the preconditioning hole into a misaligned hole.</td>
<td>1. Mine Standards. 2. Legal requirements. 3. Trained and qualified miners.</td>
<td>2 2 44</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology.</td>
</tr>
<tr>
<td></td>
<td>1b) The preconditioning hole is marked on the face in front of support that has been installed close to the face, which will cause the rock drill operator to drill a misaligned hole.</td>
<td>Human factor, as the correct marking procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Trained and qualified miners. 2. Research done on preconditioning. 3. Positive behaviour reinforcement.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes.</td>
</tr>
<tr>
<td></td>
<td>1c) The preconditioning holes are marked too close to either the footwall or hangingwall.</td>
<td>Human factor, as the correct marking procedures/standards are not adhered to. Lack of training.</td>
<td>Damage the footwall or hangingwall.</td>
<td>1. Trained and qualified miners. 2. Trained and qualified rock drill operators. 3. Research done on preconditioning. 4. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>2. Drill the hole</td>
<td>2a) The preconditioning hole/s are not drilled according to the recommended specifications which included, but is not restricted to, the following: direction, elevation and position.</td>
<td>Human factor, as the correct drilling procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations, as well as cause damage to the footwall and or hangingwall</td>
<td>1. Mine Standards. 2. Trained and qualified rock drill operators. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes should be given to all rock drill operators. 3. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
</tbody>
</table>
## PRECONDITIONING – RISK ANALYSIS TABLES

<table>
<thead>
<tr>
<th>Step</th>
<th>Hazard</th>
<th>Cause</th>
<th>Consequence</th>
<th>Existing Controls</th>
<th>Risk Index</th>
<th>Recommended controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>2b)</td>
<td>The preconditioning hole/s are not drilled to the specified length (short).</td>
<td>Human factor, as the correct drilling procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified rock drill operators. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes should be given to all rock drill operators. 3. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>2c)</td>
<td>Not all the marked preconditioning holes are drilled.</td>
<td>Human factor, as the correct drilling procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified rock drill operators. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes should be given to all rock drill operators. 3. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>2d)</td>
<td>The preconditioning hole/s are not drilled in the correct direction or drilled parallel to each other.</td>
<td>Human factor, as the correct drilling procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified rock drill operators. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes should be given to all rock drill operators. 3. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>Step</td>
<td>Hazard</td>
<td>Cause</td>
<td>Consequence</td>
<td>Existing Controls</td>
<td>Risk Index</td>
<td>Recommended controls</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>-------</td>
<td>-------------</td>
<td>-------------------</td>
<td>-----------</td>
<td>----------------------</td>
</tr>
<tr>
<td>2e)</td>
<td>Compensation for reef rolls is not taken.</td>
<td>Human factor, as the correct drilling procedures/standards are not adhered to. The roll is not timeously identified. Lack of training.</td>
<td>May cause damage to the footwall and/or hangingwall</td>
<td>1. Mine Standards. 2. Trained and qualified rock drill operators. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Additional training for the drilling of long preconditioning holes should be given to rock drill operators. 3. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>3.</td>
<td>Charge up</td>
<td>The preconditioning hole/s are over charged with explosives.</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Lack of training.</td>
<td>Cause blowouts and damage/fracture the rock as well as reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
</tr>
<tr>
<td>3a)</td>
<td>The preconditioning hole/s are under charged with explosives.</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Lack of training.</td>
<td>Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>3c)</td>
<td>The primer is not placed in the incorrect position in the hole (the bottom of the hole).</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Lack of training.</td>
<td>No effect on the preconditioning but will make the removal of any misfire more difficult.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 5 32</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
</tbody>
</table>
## PRECONDITIONING – RISK ANALYSIS TABLES

<table>
<thead>
<tr>
<th>Step</th>
<th>Hazard</th>
<th>Cause</th>
<th>Consequence</th>
<th>Existing Controls</th>
<th>Risk Index</th>
<th>Recommended controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>3d)</td>
<td>The same type of fuse for all production and preconditioning holes is not used.</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Correct fuses are not available. Lack of training.</td>
<td>Out of sequence firing causing misfires. Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 5 32</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>4. Stemming</td>
<td>4a. The preconditioning hole/s are not stemmed for 1 metre to the collar of the hole.</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Lack of training.</td>
<td>Cause blowouts and damage/fracture the rock. Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td></td>
<td>4b. Incorrect or poor quality stemming material is used to stem the preconditioning hole/s up to 1 meter.</td>
<td>Human factor as the correct charging up procedures/standards are not adhered to. Lack of training.</td>
<td>Cause blowouts and damage/fracture the rock. Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>5. Timing</td>
<td>5a) Preconditioning hole/s detonate before the production blast holes.</td>
<td>Human factors as the correct connecting up procedures/standards are not adhered to. Lack of training.</td>
<td>Cut-offs and out of sequence firing of the face holes. Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td></td>
<td>5a) Preconditioning hole/s detonate out of sequence (late).</td>
<td>Human factors as the correct connecting up procedures/standards are not adhered to. Lack of training.</td>
<td>Out of sequence firing of the face holes as well as blowouts. Reduce the effect of preconditioning and possibly result in stress concentrations.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 3 41</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
<tr>
<td>6. Blast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# PRECONDITIONING – RISK ANALYSIS TABLES

<table>
<thead>
<tr>
<th>Step</th>
<th>Hazard</th>
<th>Cause</th>
<th>Consequence</th>
<th>Existing Controls</th>
<th>Risk Index</th>
<th>Recommended controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Post examination</td>
<td>7a) Post blast examination of the preconditioning hole/s is not done.</td>
<td>Lack of training.</td>
<td>Miner will not determine if the previous day’s preconditioning was effective and if a problem did exist, no corrective action would be taken.</td>
<td>1. Mine Standards. 2. Trained and qualified Miners. 3. Supervision.</td>
<td>2 5 32</td>
<td>1. On-the-job training &amp; coaching by supervisors on the preconditioning methodology. 2. Special awareness programme (training, meetings, follow-ups, and positive behaviour reinforcement).</td>
</tr>
</tbody>
</table>