antenna is reflected strongly by fracture planes, particularly if the fractures are
open and the sides of the fractures are coated with the residues from the blast
gases. As a result, it was possible to look at the depth and intensity of fracturing
ahead of the face and, thus, to define the zone of influence of the individual
preconditioning holes. The fracture pattern ahead of a preconditioned face was
compared with that ahead of an unpreconditioned face.

A significant difference in the nature of fracturing ahead of preconditioned faces
from that ahead of unpreconditioned faces was detected from the GPR scans
and is shown in Figure 5.4.22. The density of open fractures was much higher in
preconditioned areas. In unpreconditioned areas, the depth of open fractures
ahead of the face extended to approximately 2.5 m from the stope face into the
rockmass. By contrast, in preconditioned areas, the depth of open fractures
extended 4 m from the face into the rockmass. This is shown in Figure 5.4.23.

5.4.8 Safety records

Table 5.4.6 shows the area (i.e. square metres) mined per reportable injury
related to seismicity and falls of ground that occurred in the test site panels from
May 1995 to the end of 1996. A clear increase can be seen in the rate of the area
mined per reportable injury after the introduction of preconditioning. During the
diagonal mining period, the deteriorating safety record can be attributed to the
poor face configuration (with respect to joint orientations) and the formation of
highly stressed areas adjacent to the stability pillar. After the faces were re-
established for up-dip mining, there was a significant improvement in the safety
record.

Following the termination of the preconditioning project in March 1997, both the
safety department and the rock mechanics department, as well as production
personnel, reported a deterioration in the conditions at the former project site,
including an increase in the rock-related accident rate. It is related that three sites
in the vicinity of and including the test site were damaged by large seismic events
with magnitudes in the range of 1.8 to 3.0 in the space of a single week, with 16
rockburst injuries resulting from the seismicity.
Figure 5.4.22  Ground Penetrating Radar scan of an unpreconditioned panel face and a preconditioned panel face, showing the density of open fractures.
Figure 5.4.23  
Ground Penetrating Radar scan of a preconditioned panel face, showing the depth of the remobilised fracture zone

Table 5.4.6  
Safety record for the test site after the start of the preconditioning in May 1995

<table>
<thead>
<tr>
<th>Safety Record (m² mined / injury)</th>
<th>Up-dip</th>
<th>Diagonal</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preconditioning</td>
<td>2553</td>
<td>981</td>
<td>1430</td>
</tr>
<tr>
<td>Non-preconditioning</td>
<td>735</td>
<td>377</td>
<td>562</td>
</tr>
<tr>
<td>Combined</td>
<td>937</td>
<td>528</td>
<td>741</td>
</tr>
</tbody>
</table>

5.4.9 Production

Face advance

During the preconditioning experimentation work the face advances were measured daily at both preconditioned and unpreconditioned panels from fixed
points, usually a convergence station. A significant increase in the face advance rate was noted in the preconditioned panels. The average face advance per blast was about 0.70 m in unpreconditioned panels. In preconditioned panels, however, the average face advance rate was slightly greater than 1.0 m, which represents an improvement of more than 43 percent in face advance rate.

This increased face advance rate was probably due to the opening and extending of the pre-existing fractures in the rockmass ahead of the stope face by the preconditioning blast. In addition to this, the face dilation and resultant shearing along the reef/hangingwall and reef/footwall contacts might also have contributed to the ease of face breaking. Production personnel noted that barring of the face was much easier after a preconditioning blast. The greater face advances during preconditioning might partly be the result of extensive barring of the face.

**Drilling rate**

Work done in 1995 showed that the time required to drill one 3.0 m long preconditioning hole averaged approximately 12 minutes. The up-dip panels at the project site were, on average, 17 m long and, for each panel, two drilling teams (a drill machine operator and an assistant) were allocated to drill about 60 production holes in total. Since six preconditioning holes were to be drilled in such a panel, it was thought that each drill crew would need to drill for an extra 45 minutes.

The timing of the drilling of both preconditioning and production holes was undertaken at the test panel. The detailed results of these timing studies are given in Section 5.5.6. It is important to note that the drilling of preconditioning holes as deep as 3.6 m was not an impossible task and could be completed in less than 14 minutes on average. It must also be noted that the drilling rate of production holes in preconditioned panels represented a 6 percent to 40 percent improvement over the drilling rate of production holes in unpreconditioned panels.

Preconditioning had a favourable impact on the drilling time needed per shift. Although it was initially thought that drilling crews would need extra time to drill
preconditioning holes, when the total drilling times spent by each drill crew were compared for preconditioned and unpreconditioned panels, it was seen that less time was spent drilling in preconditioned panels, despite the increased number of metres drilled. Therefore, preconditioning does not require extra time and, in fact, results in a saving of drilling time.

5.4.10 Cost analysis

The success of the implementation of preconditioning on a large scale in South African gold mines is dependent upon the economic viability of the technique. Even if a rockburst control technique can be proven to drastically reduce the risk of face bursting, its implementation will be limited to very high-grade areas if costs cannot be kept to a minimum. The cost analysis presented here was based on the actual cost of materials which were 1995 escalated stoping costs as supplied in early November 1995 (Lightfoot, et al., 1996).

This analysis contains several assumptions which are considered fairly realistic and are based on information and studies carried out by the mine's industrial engineering personnel. The main assumptions are that:

- stoping costs were based on information from stores requisitions;
- preconditioning should incur no additional material waste;
- preconditioning holes were considered safety holes and no additional money in the form of bonuses would be paid for drilling them;
- no additional labour was provided to drill the holes; and
- preconditioning took place in a timber-supported stope.

The average stores costs can be divided into the following general categories and quoted in terms of Rands per m² mined (Table 5.4.7). Certain costs could not be separated from stoping and development operations and they were, therefore, not considered in any part of this analysis. These include mainly pumping, compressed air and transportation costs.
### Table 5.4.7 Average cost for timber-supported stopes (stores and labour)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosives</td>
<td>R 18.96 / m²</td>
</tr>
<tr>
<td>Drilling - steel only</td>
<td>R 5.20 / m²</td>
</tr>
<tr>
<td>Support - timber and other</td>
<td>R 123.85 / m²</td>
</tr>
<tr>
<td>Other - incl. trackless equipment, services, scraping, etc.</td>
<td>R 38.90 / m²</td>
</tr>
<tr>
<td>Stoping stores costs (subtotal)</td>
<td>R 186.91 / m²</td>
</tr>
<tr>
<td>Labour costs - stoping</td>
<td>R 195.72 / m²</td>
</tr>
<tr>
<td>Total stoping costs</td>
<td>R 382.63 / m²</td>
</tr>
</tbody>
</table>

A detailed labour cost breakdown was not provided for 1995 but a planned average stoping cost for 1996 (including labour) was obtained from the industrial engineering personnel. From the average stoping costs for timber-supported and backfill-supported stopes and assuming that backfill accounts for only 10% of stope support, the average labour cost was estimated on the assumption that escalated 1995 and planned 1996 costs were equivalent.

Cost calculations were based on the fuse initiation system as this was used in the project site. The implementation of preconditioning with such an initiation system resulted in the entire panel changing to longer (2.1 m) fuses to prevent confusion during charging operations. The assumptions regarding the implementation of preconditioning are that:

- the entire panel used 2.1 m long fuses;
- the same explosive Powergel 816 was used in the preconditioning holes and production holes;
- every preconditioning hole was tamped with clay cartridges;
- preconditioning holes were drilled to a depth of 3.0 m;
- 38 mm “knock-off” bits could drill a total hole length of 80 m before being replaced;
- each drill stem lasted for a total hole length of 210 m;
- the rock drill used was the new Seco Nova 70. Costs were depreciated over five years; and
- production holes were 1.15 m long, with 30 holes per shift and 20 shifts per month.
The cost to drill one preconditioning hole was calculated on the basis of the assumptions listed above and is given in Table 5.4.8.

### Table 5.4.8 Normalised cost to drill and blast one 3.0 m preconditioning hole

<table>
<thead>
<tr>
<th>Explosives:</th>
<th>Powergel 816 -15 cartridges 25 mm x 200 mm</th>
<th>R 6.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuse 2.1 m long</td>
<td>R 1.47</td>
</tr>
<tr>
<td></td>
<td>Tamping - 8 clay cartridges</td>
<td>R 1.16</td>
</tr>
<tr>
<td></td>
<td>Subtotal - explosives</td>
<td>R 8.63</td>
</tr>
<tr>
<td>Drilling:</td>
<td>38 mm bit</td>
<td>R 2.02</td>
</tr>
<tr>
<td></td>
<td>3.2 m drill stem</td>
<td>R 2.05</td>
</tr>
<tr>
<td></td>
<td>Rock drill</td>
<td>R 0.62</td>
</tr>
<tr>
<td></td>
<td>Subtotal - drilling</td>
<td>R 4.89</td>
</tr>
<tr>
<td></td>
<td><strong>Total cost of one preconditioning hole</strong></td>
<td>R 13.32</td>
</tr>
</tbody>
</table>

To extend these costs into one full-production blasted shift, it is assumed that the face length is 15 m long. This requires five preconditioning holes and 60 production holes to be drilled. The production blast results in a 1.0 m average face advance. The cost per blasted shift is shown in Table 5.4.9 and is R 5.88/m². Table 5.4.10 compares this to the cost of stoping in terms of stores costs only and total cost including labour. Since it is assumed that there is no additional labour involved with preconditioning, the additional cost to the normal stoping operation is 1.5 percent.

### Table 5.4.9 Total cost of preconditioning for one production blast

<table>
<thead>
<tr>
<th>Five preconditioning holes</th>
<th>R 66.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional cost of longer fuses for 60 production holes</td>
<td>R 21.60</td>
</tr>
<tr>
<td>Total preconditioning cost per blast</td>
<td>R 88.20</td>
</tr>
<tr>
<td>Preconditioning cost per m² (R 88.20 / 15 m²)</td>
<td>R 5.88</td>
</tr>
</tbody>
</table>

It was observed that the average face advance per blast prior to the preconditioning of a panel was 0.7 m. This rate was increased to an average of 1.0 m face advance per blast in the preconditioned panels (Section 5.4.9). This
Increased face advance rate resulted in a considerable improvement in productivity and, thus, a reduction in production cost. A 43 percent improvement in face advance does not, however, relate to an equivalent reduction in stoping costs as some items are not affected by production rate, such as support and cleaning costs. The costing areas noted in Table 5.4.7 that are affected by the increased productivity include drilling, blasting and labour. Table 5.4.11 compares the total cost of the implementation of preconditioning, including the cost benefit obtained by the increased face advance. A stoping cost reduction of R 60/m² or 15.7 percent is directly attributable to the increased face advance in preconditioned panels.

### Table 5.4.10 Comparison of the cost of preconditioning to normal stoping costs

<table>
<thead>
<tr>
<th></th>
<th>Stoping cost (R / m²)</th>
<th>Percentage cost increase with preconditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preconditioning cost</td>
<td>5.88</td>
<td></td>
</tr>
<tr>
<td>Stoping stores cost</td>
<td>186.91</td>
<td>3.1 %</td>
</tr>
<tr>
<td>Total stoping cost</td>
<td>382.63</td>
<td>1.5 %</td>
</tr>
</tbody>
</table>

### Table 5.4.11 Comparison of total costs per m² with and without preconditioning

<table>
<thead>
<tr>
<th></th>
<th>Cost of stoping without preconditioning</th>
<th>Cost of stoping with preconditioning</th>
<th>Cost of stoping costs with the implementation of preconditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost of stoping without preconditioning</td>
<td>Cost of stoping with preconditioning</td>
<td>Cost of stoping costs with the implementation of preconditioning</td>
</tr>
<tr>
<td>Drilling</td>
<td>R 5.20</td>
<td>R 3.64</td>
<td>R 1.56</td>
</tr>
<tr>
<td>Blasting</td>
<td>R 18.98</td>
<td>R 13.27</td>
<td>R 4.32</td>
</tr>
<tr>
<td>Stores</td>
<td>R 162.75</td>
<td>R 162.75</td>
<td>-</td>
</tr>
<tr>
<td>Labour</td>
<td>R 195.72</td>
<td>R 137.00</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>R 382.63</td>
<td>R 315.66</td>
<td>R 5.68</td>
</tr>
</tbody>
</table>

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5.5 Optimisation of the technique

In order to optimise the face-perpendicular preconditioning technique with respect to blast parameters such as hole length, hole diameter, hole spacing and amount of explosive, an optimisation experiment was initiated at the end of August 1996 at the research site. The effects of varying the lengths of preconditioning holes were investigated, using the available drill-steels at the mine (i.e. 2.4 m, 3.2 m and 3.8 m). Each of these drill-staff lengths was used for a minimum of two weeks for the purpose of drilling the preconditioning holes. Initially, these holes were drilled with a 36 mm bit but, after the initial six-week period, the bit size was changed to 40 mm. This was done to examine the effect of changing the hole diameter and hence the amount of explosive on the effectiveness of preconditioning.

Measurements used to examine and quantify the effects of the above-mentioned changes in blast parameters were:

- seismic activity;
- rockmass fracturing;
- hangingwall profiles;
- Ground Penetrating Radar;
- stope convergence; and
- impact on production (face advance and drilling times).

5.5.1 Seismic activity

In this section, the discussion of the analysis and interpretation of the recorded seismicity concentrates on the period of the preconditioning optimisation study, during which the mining activity and the application of preconditioning were better controlled.

The seismic data recorded by the PSS from the vicinity of the test site between 26 August and 20 October 1996 is shown in Figure 5.5.1. The seismicity was clearly clustered into distinct spatial groupings associated with the areas of active
mining in the 84-49W stope, 87-49W stope, 89-49 stope and the slopes to the east. In this figure, 927 seismic events are plotted with magnitudes of between -1.54 and 2.86. The mining of the test stope occurred in three panels, labelled 'W1', 'W1a' and 'W3', as shown in Figure 5.5.2. The W3 panel was the site of the optimisation experiment, while W1 and W1a panels were mined without preconditioning during this period. Of the latter two panels, W1a served as the more natural control panel, W1 being situated in a relatively low-stress environment at the bottom of the stope.

Figure 5.5.1 Seismic data recorded from 26/08/96 to 20/10/96 by Portable Seismic System

The seismic data recorded from the test site between 26 August and 20 October is shown in plan in Figure 5.5.3. In this figure, 380 seismic events are plotted with magnitudes greater than -1.5. The clusters of seismicity associated with the
blasting of the footwall development and of a new travelling way into the stope are clearly evident in Figure 5.5.3, as are the clusters associated with the up-dip mining of the three panels. Some seismic activity associated with the formation of the stability pillar at the top of the stope is also indicated in Figure 5.5.3.

Figure 5.5.2 Plan of the test site, showing three actively mined up-dip panels

The proportions of recorded seismic events of various magnitudes are shown in Figure 5.5.4, which is a frequency-magnitude graph in which the number of events of magnitude greater than or equal to a given magnitude is plotted versus magnitude. The slope of the linear portion of the graph yields the b-value, which gives an indication of the relative proportions of larger and smaller seismic events. A lower b-value indicates that more seismic energy is being released via a relatively large number of larger events. A b-value of about 0.5 is fairly typical of deep-level longwall mining environments. The graph in Figure 5.5.4 also provides useful information in terms of the recording system. The minimum magnitude ($M_{min}$) of -0.79 indicates that seismic events of a magnitude smaller than this are not reliably detected by the system. The departure from linearity at larger
magnitudes (M>1) reflects the fact that the recorded waveforms for larger seismic events tend to saturate and so produce less accurate magnitude estimates.

Figure 5.5.3 Seismic data recorded between 26/08/96 and 20/10/96 from the test site by PSS

A graph of the cumulative seismicity recorded from the test slope is shown in Figure 5.5.5. The seismicity rate was fairly uniform during this period. The plot in Figure 5.5.5 gives a clear indication of the periodic reduction in seismicity rate associated with the lack of mining activity over weekends. The influence of blasting on recorded seismicity suggested by Figure 5.5.5 is confirmed in Figure 5.5.6, which shows the diurnal distribution of the same subset of seismicity. The seismicity rate very clearly peaks at the times of blasting on the mine (after 13:00 for development blasting and after 17:00 for production blasting). Fully 86 percent of the seismic events were recorded in the time period between 12:00 and 20:00. The peak for development blasting is higher than that for production blasting (Figure 5.5.6), as the development blasts are larger, so that more of the actual
blasts were recorded (while much of the seismicity recorded during production blasting consists of seismic events triggered by the blasting).

Figure 5.5.4 Frequency-magnitude distribution of seismic data recorded from the test site between 26/08/96 and 20/10/96 by PSS

Figure 5.5.5 Cumulative number of seismic events recorded from the test by PSS
Figure 5.5.6 Diurnal distribution of seismic data recorded from the test stope between 26/08/96 and 20/10/96 by PSS

Three "seismogenic regions" were defined from the seismicity associated with the mining of the three panels in the test site during the period of the optimisation study. These are shown by dashed rectangles in Figure 5.5.7. These defined regions are offset somewhat to the West from the physical positions of the panels themselves, due to the effect of the mined-out ground to the East. The seismic waves travelled faster through the unmined ground to reach site OS2 than through the mined-out ground to reach the other four sites, so that the seismic events were located slightly to the West of their actual positions as a result of the use of a constant-velocity model for the rockmass.

The preconditioning optimisation experiment passed through four stages, each characterised by the use of different drill-steel lengths and/or drill-bit diameters in the drilling of the face-perpendicular preconditioning holes in W3 panel. The seismic data recorded during each of the four stages is shown in plan in Figure 5.5.8. Production activity in W1a panel was stopped as a result of damage produced by a pair of large (M>1) seismic events, which occurred at the end of
the third stage, so that little seismicity was recorded from W1a panel during the fourth stage (Figure 5.5.8 d).

![Diagram showing seismogenic regions](image)

**Figure 5.5.7 Plan of the test stope showing the seismogenic regions**

Some 21 large (M>1) seismic events were recorded from the test stope during the period of the optimisation study and these are shown in Figure 5.5.9. Two of these events occurred virtually simultaneously on 5 October 1996. Their locations are indicated by the white stars in Figure 5.5.9. One of these events occurred ahead of the face of W1a panel and resulted in extensive damage to the panel, and consequently the mining of the panel was stopped for almost two weeks for rehabilitation. The second event occurred close to W3 panel and resulted in very minor damage in the form of shake-down from the area of fracturing induced by the influence of the prior "diagonal" mining configuration. Production activity recommenced in W3 panel on the following working day. Four other large seismic events occurred in close proximity to W3 panel during the period of the optimisation study, none of them causing noticeable damage to the panel.
Figure 5.5.8 Plan of test site stope showing seismic activity recorded during four phases of the preconditioning optimisation study

The seismic data recorded from the test stope during the period are summarised in Table 5.5.1. The percentages of larger seismic events recorded from the three panels were higher than those from the stope as a whole, as the stope seismicity included large numbers of development blasts, which were recorded as seismic events of magnitude M<0. The seismic characteristics of W3 panel, in terms of the proportions of larger events and of the distribution of seismicity with respect to blasting time, were very similar to those of the control panel, i.e. W1a panel, for the subset of seismicity defined by the limited sensitivity of the monitoring system. It is of interest that the distribution of larger events mimics that of the
recorded seismicity as a whole with respect to blasting time, although a greater proportion of M>1 seismic events occurred with production blasts (rather than with development blasts), reflecting the greater effectiveness of such blasts in releasing seismic energy from the rockmass.

Figure 5.5.9 Seismic events of M>1 recorded from the test site between 26/08/96 and 20/10/96 by PSS.

Table 5.5.1 Summary of seismic data recorded during preconditioning optimisation study

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>M&gt;0</th>
<th>M&gt;1</th>
<th>% During Blasting Time**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>M&gt;0</td>
<td>M&gt;1</td>
<td>Number</td>
</tr>
<tr>
<td>87-49W</td>
<td>380</td>
<td>107</td>
<td>20</td>
<td>88</td>
</tr>
<tr>
<td>W3</td>
<td>52</td>
<td>25</td>
<td>5</td>
<td>85</td>
</tr>
<tr>
<td>W1a</td>
<td>45</td>
<td>24</td>
<td>4</td>
<td>80</td>
</tr>
<tr>
<td>W1</td>
<td>54</td>
<td>28</td>
<td>6</td>
<td>72</td>
</tr>
</tbody>
</table>

*Seismicity recorded between 26/08/96 and 20/10/96
**Blasting time: 12:00 to 20:00
Another evidently significant result which has emerged from this study is that no seismic activity was recorded from the vicinity of W3 panel between 20:00 and 04:00 during the period of the study. This can be seen in Figure 5.5.10. This suggests that the preconditioning blasting was effectively distressing the rockmass ahead of the panel face, and that the effect of this distressing remained for some time after the production blast. The implication is that the panel was made safer, at least for the period during which the night shift was present in the stope.

![Graph showing diurnal distribution of seismic data](image)

**Figure 5.5.10** Diurnal distribution of seismic data recorded from the test stope W3 panel between 25/08/96 and 20/10/96 by PSS

### 5.5.2 Rockmass fracturing

During the optimisation phase, minor variations in the fracture pattern were observed with the various depths of preconditioning and various blast diameters. These differences, while measurable, were less significant than those observed...
when ground conditions in the preconditioned and unpreconditioned panels were compared. With an increase in drill-steel length, fractures tended to become slightly shallower dipping, with a decrease in the number of fractures. This tendency can be seen in Figure 5.5.11.

![Diagram showing Schmidt-net (lower hemisphere projection) of poles to all fractures mapped during the optimisation phase](image)

Figure 5.5.11  Schmidt-net (lower hemisphere projection) of poles to all fractures mapped during the optimisation phase

Fractures that developed during the use of the 3.8 m long drill-steel showed less variation in strike than the ones that formed when a 3.2 m long drill-steel was used to drill preconditioning holes, and this reduced variation is shown in Figure 5.5.12. This was particularly apparent when the 40 mm diameter bit was introduced with the 3.2 m long drill-steel. This change was most likely due to the position at which the fractures were remodelled. Owing to greater confinement further ahead of the face, the orientation of the intermediate principal stress was limited to a narrower range, and hence fracturing was restricted to a more-or-less
face-parallel orientation. With slightly shorter holes, the blast was not as confined and the fractures that were re-activated could have had a greater range in strike orientations but, once again, these were mainly face-parallel.

2.4 m drill steel

3.2 m drill steel

orientation of face

3.8 m drill steel

40 mm bit

Figure 5.5.12 Rose diagrams showing orientation of fractures mapped during the optimisation phase
From the fracture mapping data, it would appear that the 3.2 m long drill-steel with a 40 mm bit was the most effective at remobilising the fractured rockmass within the reef horizon, while restricting the extent of damage to the hangingwall.

5.5.3 Hangingwall profiles

One of the beneficial side effects of preconditioning is an improvement in the quality of the hangingwall conditions. An attempt was made to quantify this effect through the measurement of the profiles of the hangingwall. With increasing drill-steel length and a subsequent increase in bit diameter the quality of the hangingwall was seen to improve.

The data obtained from the profile measurements in the hangingwall showed that both the gradient and profile length decreased, indicating a smoother and, hence, better quality hangingwall. This is shown in Figure 5.5.13. Increasing the preconditioning hole length resulted in an overall decrease in profile length and gradient, indicating an improved hangingwall. All preconditioning scenarios showed significantly smoother hangingwall profiles compared with those from an unpreconditioned panel. The smoother hangingwall resulted from the combined effect of fewer fractures in the hangingwall and of decreased penetration of those that did occur, compared with unpreconditioned areas.

5.5.4 Ground Penetrating Radar surveys

After testing different preconditioning hole lengths and diameters, optimisation work was continued in an attempt to determine the zone of influence of the individual preconditioning blastholes and, consequently, the optimum spacing between them. In order to achieve this, Ground Penetrating Radar (GPR) was employed.
The results of GPR work proved very successful in delineating the extent of re-activation of fractures around a preconditioning hole and ahead of a preconditioned face. Figure 5.5.14 and Figure 5.5.15 show annotated radar scans superimposed on the positions of mapped preconditioning holes. These figures clearly illustrate the zones of influence of the individual preconditioning blasts. Analysis of the GPR data indicated that the effective zone around each preconditioning hole extended for about 4 m along the slope face. A spacing of greater than 4 m between adjacent holes resulted in an unpreconditioned zone between two preconditioning holes, and this is shown in Figure 5.5.14.

Figure 5.5.15 shows that two of the preconditioning holes were not drilled on the previous day and, hence, none of the pre-existing fractures were opened up at those positions.
Figure 5.5.14  Ground Penetrating Radar scan, showing ineffective preconditioning when the spacing is greater than 4 m
Figure 5.5.15  Ground Penetrating Radar scan, showing the zone of influence of preconditioning holes

*** This is a continuous scan. The figure on the right is the continuation of the one on the left.
5.5.5 Convergence measurements

Convergence measurement stations were installed throughout the period of the preconditioning project at the test site and continued to operate during the optimisation programme. Six convergence stations were installed. The measurements taken during the programme are plotted in Figure 5.5.16. The ground behaviour recorded for all the stations was consistent with a high initial convergence rate and then a steadily decreasing convergence rate with increasing distance to face. Except for a very high convergence rate of 20.45 mm/m at a distance of between 7 m and 12 m from the face during the period that 3.2 m long drill-steeles were used, no other significant change in convergence rate can be seen that would correspond to the change from one preconditioning scenario to another (Figure 5.5.16).

![Figure 5.5.16: Convergence measurements in the test panel during optimisation work](image)

**Note:** Rates are given in mm/day and mm/m face advance at varying distances from the face (in brackets).
The high convergence (~50 mm) measured on 7 October 1996 was the result of the two large seismic events on 5 October 1996 shown in Figure 5.5.9. The change to 3.2 m drill-steels and 40 mm bits was made after these large events.

5.5.6 Production

Face advance

During the preconditioning trials, in addition to the safety benefits of preconditioning, a significant increase in the face advance rate was noted. This is consistent with the improved fragmentation discussed earlier and was due mainly to the opening and extending of the pre-existing fractures in the reef as a result of the preconditioning blast. In addition to this, the face dilation and resultant shearing along the reef / hangingwall and reef / footwall contacts, caused by preconditioning, also contributed to the ease of face breaking. The production personnel reported that the barring of the face was much easier after a preconditioning blast. The greater face advances during preconditioning were probably partly the result of extensive barring of the face.

During the optimisation work, the face advances were measured daily at the test panel from fixed points (e.g. a convergence station). The results of these measurements are summarised in Table 5.5.2.

The greatest average face advance was achieved when the preconditioning holes were drilled with 3.2 m long drill-steels and 36 mm drill bits. However, because of the limited number of observations this is a tentative conclusion. Increased data points could result in another preconditioning scenario achieving better average face advance rate. The results do, however, confirm the findings discussed in Section 5.4.9. These were that the average face advance rate in preconditioned panels was over 43 percent greater than in unpreconditioned panels.
Table 5.5.2 Comparison of face advance rates in preconditioned and unpreconditioned adjacent panels in the test stope

<table>
<thead>
<tr>
<th>Scenario*</th>
<th>Number of measurements</th>
<th>Face advance (metres per blast)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Unpreconditioned</td>
<td>30</td>
<td>0.55</td>
</tr>
<tr>
<td>Preconditioning</td>
<td>20</td>
<td>0.80</td>
</tr>
<tr>
<td>(2.4 m, 36 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preconditioning</td>
<td>8</td>
<td>0.80</td>
</tr>
<tr>
<td>(3.2 m, 36 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preconditioning</td>
<td>8</td>
<td>0.90</td>
</tr>
<tr>
<td>(3.8 m, 36 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preconditioning</td>
<td>7</td>
<td>0.90</td>
</tr>
<tr>
<td>(3.2 m, 40 mm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Preconditioning holes described by drill-steel length and bit diameter

Drilling rates

The timing studies for the drilling of both preconditioning and production holes were undertaken at the test panel during the optimisation work. The results of these studies are tabulated in Table 5.5.3 and Table 5.5.4. Table 5.5.3 shows that as the hole length increased so did the drilling time. However, this increase was not uniform. It took about one minute longer to drill 3.0 m holes than it did to drill 2.2 m holes and about two minutes longer to drill 3.8 m holes than 3.0 m holes. This was most likely due to the increased stress encountered further ahead of the face, which would make it more difficult to drill. The best drilling rate was achieved with a 3.2 m long drill-steel and 40 mm diameter drill-bit. Although the area to be drilled was increased by 23 percent by using a 40 mm diameter drill bit, the additional button on the 40 mm drill bits compensated for this. The increase in the amount of explosive and resultant fracturing also contributed to the improved drilling rate for subsequent holes. It is important to note that the drilling of preconditioning holes as deep as 3.5 m was not an impossible task and could be completed in less than 15 minutes.
Table 5.5.3 Comparison of drilling rates of preconditioning holes

<table>
<thead>
<tr>
<th>Scenario*</th>
<th>Number of data</th>
<th>Minimum time</th>
<th>Average time</th>
<th>Maximum time</th>
<th>Average (metre / min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preconditioning (2.4 m, 36 mm)</td>
<td>11</td>
<td>10'00&quot;</td>
<td>11'38&quot;</td>
<td>12'59&quot;</td>
<td>0.19</td>
</tr>
<tr>
<td>Preconditioning (3.2 m, 36 mm)</td>
<td>12</td>
<td>10'30&quot;</td>
<td>12'37&quot;</td>
<td>14'18&quot;</td>
<td>0.24</td>
</tr>
<tr>
<td>Preconditioning (3.8 m, 36 mm)</td>
<td>13</td>
<td>12'59&quot;</td>
<td>14'31&quot;</td>
<td>15'55&quot;</td>
<td>0.25</td>
</tr>
<tr>
<td>Preconditioning (3.2 m, 40 mm)</td>
<td>16</td>
<td>8'38&quot;</td>
<td>10'45&quot;</td>
<td>12'35&quot;</td>
<td>0.28</td>
</tr>
</tbody>
</table>

*Preconditioning holes described by drill-steel length and bit diameter

Table 5.5.4 Comparison of drilling rates of production holes for adjacent preconditioned and unpreconditioned panels

<table>
<thead>
<tr>
<th>Scenario*</th>
<th>Number of data</th>
<th>Minimum time</th>
<th>Average time</th>
<th>Maximum time</th>
<th>Average (metre / min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpreconditioned</td>
<td>28</td>
<td>4'34&quot;</td>
<td>5'08&quot;</td>
<td>5'51&quot;</td>
<td>0.21</td>
</tr>
<tr>
<td>Preconditioning (2.4 m, 36 mm)</td>
<td>6</td>
<td>3'56&quot;</td>
<td>4'46&quot;</td>
<td>5'50&quot;</td>
<td>0.23</td>
</tr>
<tr>
<td>Preconditioning (3.2 m, 36 mm)</td>
<td>8</td>
<td>3'00&quot;</td>
<td>3'57&quot;</td>
<td>5'10&quot;</td>
<td>0.28</td>
</tr>
<tr>
<td>Preconditioning (3.8 m, 36 mm)</td>
<td>11</td>
<td>2'30&quot;</td>
<td>3'05&quot;</td>
<td>3'55&quot;</td>
<td>0.36</td>
</tr>
<tr>
<td>Preconditioning (3.2 m, 40 mm)</td>
<td>14</td>
<td>1'56&quot;</td>
<td>3'14&quot;</td>
<td>4'31&quot;</td>
<td>0.34</td>
</tr>
</tbody>
</table>

*Preconditioning holes described by drill-steel length and bit diameter

Considering Table 5.5.4 it can be seen that preconditioning significantly improves the drilling rate of production holes. This had a favourable impact on the time the drilling team spent on drilling during a shift. All of the preconditioning scenarios had higher drilling rates than the unpreconditioned case. If the total drilling times are compared in unpreconditioned and preconditioned panels, it can be seen that
less time is actually spent drilling in preconditioning panels, despite the greater number of metres that need to be drilled, as seen in Figure 5.5.17.

Figure 5.5.17 Actual drill times spent per crew to drill 32 production and three preconditioning holes

5.6 Preconditioning in high-stopping-width areas

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 stopping widths. Following the completion of the research project certain mines tried to implement the technique in faceburst-prone high-stopping-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 these implementation attempts were unsatisfactory was unknown. There was a clear need for re-establishing the best preconditioning practice and formulating the guidelines for high-stopping-width mining activities in different geotechnical areas where facebursting had become a problem. Therefore, CSIR / Miningteck’s preconditioning research team initiated a
two-year research project, sponsored by SIMRAC, with the following main objectives:

- to investigate the reasons that the current design of the technique could not meet the faceburst control requirements in high-stopping-width areas;
- to identify the blast parameters that need to be modified and optimised for these areas;
- to update the preconditioning guidelines for varying stopping widths;
- to list the measures to determine the effectiveness of the preconditioning technique;
- to consolidate the recommendations on how best this technology can be transferred to the industry; and
- to produce interactive training modules and a booklet for demonstrating the technique.

Only a brief summary of this very comprehensive research project is provided here. For this reason, readers are referred to Topar et al. (2003) for detailed information.

5.6.1 Summary of findings

A few experimental sites (e.g. 94/44 VCR, 109/48 VCR and 109/51 VCR stopes at Mponeng gold mine) were established in high-stopping-width areas and the research team ensured that preconditioning was implemented regularly and properly at 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 (Figure 5.6.1 and Figure 5.6.2) could not be eliminated when the preconditioning holes were drilled in the middle of the stope height (i.e. equal or greater than 1 m from the contact between the reef and hangingwall). When preconditioning holes were positioned at about 60 cm below the contact between the reef and hangingwall, overhanging face shapes were eliminated and improved hangingwall conditions were observed (Figure 5.6.3).

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