introduction of preconditioning. This further illustrates the importance of a subjective evaluation of how people's attitudes change as preconditioning is introduced.

Figure 5.3.5 Seismic events of $M \geq 1$ recorded from the test site between 26/08/96 and 20/10/96

Since worker perceptions are of considerable importance for the future acceptability of preconditioning as an implementable production tool, it was decided to undertake studies of worker attitudes towards preconditioning. Schuitema Associates, independent consultants who specialise in human resource management, were contracted to assist in the interviewing of mining personnel to assess their attitudes towards safety in seismically active areas and the role of preconditioning in improving safety. The objective of the survey was to evaluate workers' views on methods of training in order to facilitate the effective implementation of preconditioning on the mines.
The survey was completed at the test site. It was found that the mine personnel perceived that preconditioning had a positive effect on the mining environment. They stated that no rockburst has been experienced at preconditioning panels, although large seismic events had occurred. They considered themselves to be safer working in the preconditioned panels and acknowledged that there had been physical improvements in the environment. These included superior hangingwall conditions and a softer face that was easier to mine. The mine personnel also acknowledged that the injury rate and severity of injuries had been reduced. They also noticed a significant improvement in the production rate in the preconditioned panels. On the other hand, practical concerns included the time required to drill the longer holes with inadequate air pressure, and difficulties in withdrawing drill jumpers from the longer holes. In addition, the workers perceived that the preconditioning activity involved extra work for which they considered they should receive extra payment.

Although the results of the preconditioning experiment were received enthusiastically by all concerned production personnel on the mine, preconditioning was discontinued at the test site after the cessation of the project work on the mine. The main reason for this was that no extra payment was made for what workers perceived as an increased workload.

5.4 Quantitative analysis of the effects of preconditioning

Owing to the need to quantify the effects of preconditioning on the rockmass in the vicinity of the preconditioning face, a large data set was compiled during the monitoring of the face perpendicular preconditioning experiment in the test site. This data set consisted of information on many aspects of the rockmass response to mining and preconditioning. The data obtained from the monitoring programme led to a greater understanding of the rockmass response and confirmed the effectiveness of preconditioning. This data set comprised:

- seismic measurements;
- convergence measurements;
• fracture mapping;
• hangingwall profiling;
• stress determination;
• rock fragmentation analysis;
• Ground Penetrating Radar (GPR) surveys;
• safety records;
• production figures; and
• cost analysis.

5.4.1 Seismic activity

A large seismic database from the test site and surrounding areas was compiled through the use of the PSS records from the preconditioning site. The data appeared to be well correlated with the data from adjacent PSS network and data from the mine-wide microseismic network. Spatially, the seismicity recorded independently by both PSS networks exhibited similar trends, with a marked degree of clustering in the vicinity of the 84-49W, 87-49W test site and 89-49W slope faces, as shown in Figure 5.4.1. The linear spatial clustering of seismicity ahead of the 87-49W test site faces was more intense than that ahead of the 84-49W faces, where the stress conditions appeared to be modified by the presence of both the stability pillar to the north and the geological structures to the west. Both networks recorded a higher seismicity rate from 87-49W than from 84-49W and the seismic b-values were lower, indicating that there was a higher proportion of larger seismic events. This indicates that the test site was the more seismically active area. A comparison of data recorded by the two PSS networks between September 1994 and April 1995 is given in Table 5.4.1.

The overall sensitivity of the PSS at the preconditioning site was greater than the PSS monitoring the stability pillar, with the result that the former network recorded seismic events of smaller magnitudes. At the other end of the magnitude scale, the waveforms from the preconditioning PSS were saturated for local larger events, so that the magnitudes assigned to such larger events were less accurate. Clearly, the sensitivity and location accuracy of each network were better for the seismicity from the particular slope that was closest to that network.
The estimated location errors given in Table 5.4.1 were somewhat inflated by the fact that the simple velocity model used in the location error calculation of the recorded seismic events averaged out the differing hangingwall (lava) and footwall (quartzite) P- and S-wave velocities for the rockmass in the area. The location accuracy of each network was better than the quoted figure for the seismicity local to that network, because of the encompassing of each stope in the monitored area by the respective network configuration, and the fact that the least squares algorithm used to locate the events was independent of the velocity model.

Figure 5.4.1 Plan of the seismicity recorded from the preconditioning test site during 1995 (seismic events of magnitude \( M \geq 0 \) are shown)
Table 5.4.1 Comparison of seismic data recorded by two adjacent PSS networks on WDL South Mine

<table>
<thead>
<tr>
<th></th>
<th>Project Site PSS</th>
<th>Stability Pillar PSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismicity from 84-49W stope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of events</td>
<td>303</td>
<td>280</td>
</tr>
<tr>
<td>Smallest magnitude</td>
<td>-0.98</td>
<td>-1.39</td>
</tr>
<tr>
<td>Average magnitude</td>
<td>-0.15</td>
<td>-0.15</td>
</tr>
<tr>
<td>Largest magnitude</td>
<td>1.94</td>
<td>1.58</td>
</tr>
<tr>
<td># of M&gt;0 events</td>
<td>103</td>
<td>103</td>
</tr>
<tr>
<td>b-Value</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td>Average estimated location error (m)</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>Seismicity from 87-49W stope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of events</td>
<td>1275</td>
<td>379</td>
</tr>
<tr>
<td>Smallest magnitude</td>
<td>-1.83</td>
<td>-1.18</td>
</tr>
<tr>
<td>Average magnitude</td>
<td>-0.49</td>
<td>0.03</td>
</tr>
<tr>
<td>Largest magnitude</td>
<td>2.08</td>
<td>2.40</td>
</tr>
<tr>
<td># of M&gt;0 events</td>
<td>257</td>
<td>177</td>
</tr>
<tr>
<td>b-Value</td>
<td>0.71</td>
<td>0.65</td>
</tr>
<tr>
<td>Average estimated location error (m)</td>
<td>17</td>
<td>20</td>
</tr>
</tbody>
</table>

The seismic data recorded by the preconditioning PSS exhibited a well-developed clustering ahead of the preconditioning stope faces in plan and, to a lesser extent, about the plane of the reef in section. The shape of the clustering in plan approximated the mining geometry and there was evidence that the seismicity migrated along the advancing stope faces. The recorded seismicity rate had two clear peaks over a period of a day, corresponding to development blasting at about 15:00 and to production blasting in the stope at about 17:00.

From September 1994 until the commencement of preconditioning in May 1995, a background database of seismicity was recorded from 87-49W stope by the preconditioning site PSS. From 23 May 1995 to 14 August 1995, a single up-dip panel labelled ‘E’ in Figure 5.4.2 was preconditioned. The location accuracy of
the manually located seismic data was sufficient to allow the comparison of the seismic characteristics of the preconditioned and adjacent panels before and after preconditioning, but not good enough for the expected stress-transfer processes induced by preconditioning ahead of the panel face to be identified. Changes in the spatial location of the seismicity with respect to the panel face were expected to be relatively small compared with the distinct effect observed in the seismicity recorded after a face-parallel preconditioning blast.

Figure 5.4.2 Plan of preconditioning site, showing mining faces

A comparison of the seismicity recorded from the preconditioning panel 'E' and from adjacent panels ('D' and 'C' to the east of panel 'E'; and 'F' to the west) before and during the preconditioning of panel 'E' is given in Table 5.4.2.

The change in the number of seismic events recorded from the various panels between the two time periods reflects the fact that the mining activity shifted from the eastern portion of the stope around panel 'C' to the western portion around panel 'F'. While there were changes in the seismic characters of the adjacent panels after the start of preconditioning in panel 'E', the change within panel 'E' itself was clearly the most significant. This was expected as the effects of preconditioning were thought to be confined mostly to the rockmass in the
immediate vicinity of the preconditioning blast. The seismic data contained no
indications of any preconditioning effect (positive or negative) on the panels
adjacent to panel ‘E’.

Table 5.4.2  Summary of seismic data recorded before and after the
initiation of preconditioning panel ‘E’ of the test site

<table>
<thead>
<tr>
<th>Panel</th>
<th>Period *</th>
<th>b-Value **</th>
<th>Total events</th>
<th>% M≥0 events</th>
<th>Average kappa (ms) **</th>
</tr>
</thead>
<tbody>
<tr>
<td>'C'</td>
<td>before</td>
<td>0.53±0.15</td>
<td>53</td>
<td>26.4</td>
<td>1.62±0.41</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.47±0.17</td>
<td>30</td>
<td>30.0</td>
<td>1.53±0.47</td>
</tr>
<tr>
<td></td>
<td>% change</td>
<td>-11.3</td>
<td>-43.4</td>
<td>13.6</td>
<td>-5.6</td>
</tr>
<tr>
<td>'D'</td>
<td>before</td>
<td>0.48±0.18</td>
<td>29</td>
<td>20.7</td>
<td>1.65±0.56</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.58±0.18</td>
<td>39</td>
<td>17.9</td>
<td>1.58±0.40</td>
</tr>
<tr>
<td></td>
<td>% change</td>
<td>20.8</td>
<td>34.5</td>
<td>-13.5</td>
<td>-4.2</td>
</tr>
<tr>
<td>'E'</td>
<td>before</td>
<td>0.42±0.16</td>
<td>28</td>
<td>53.6</td>
<td>1.79±0.55</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.60±0.16</td>
<td>58</td>
<td>24.1</td>
<td>1.59±0.42</td>
</tr>
<tr>
<td></td>
<td>% change</td>
<td>42.9</td>
<td>107.1</td>
<td>-55.0</td>
<td>-11.2</td>
</tr>
<tr>
<td>'F'</td>
<td>before</td>
<td>0.55±0.23</td>
<td>25</td>
<td>32.0</td>
<td>1.71±0.49</td>
</tr>
<tr>
<td></td>
<td>after</td>
<td>0.51±0.10</td>
<td>109</td>
<td>33.0</td>
<td>1.61±0.47</td>
</tr>
<tr>
<td></td>
<td>% change</td>
<td>-7.3</td>
<td>336.0</td>
<td>3.1</td>
<td>-5.8</td>
</tr>
</tbody>
</table>

* Period before: 01/01/95 to 22/05/95 and after: 23/05/95 to 14/08/95.

** The values for b-value and kappa are given as average value ± standard
deviation.

The change in the seismic character of panel ‘E’ was most encouraging in terms
of indicating the positive effectiveness of preconditioning. The seismic b-value
increased markedly, indicating that the proportion of larger seismic events
recorded from the panel had decreased. This is confirmed by the
55 percent decrease in the proportion of M≥0 events recorded from the panel.
The manner of seismic energy release from the rockmass ahead of the panel
face had been positively altered by the introduction of preconditioning.

The attenuation factor “kappa” is an indicator of the quality of the rock in the
vicinity of the source of a seismic event. A higher value for kappa indicates that
rock is relatively more fractured. After the change to preconfining, the
maximum value of kerosene decreased by twice as much as for the permeability recorded
from panel B, than it did for that recorded from the adjacent panels. This would
suggest that the permeability ahead of the face of panel B occurred further ahead
of the face (i.e. in the least fractured ground) under the influence of
preconfining. What can be inferred here is that the preconfining increased
the stress concentration ahead of the advancing panel face away from the
evacuation, further ahead of the face and into the area of more solid rock.

5.4.2 Convergence Measurements

A total of 51 convergence stations were installed and measured at the project site
during the monitoring programme in order to capture any change in the
performance of the rockmass ahead of a single face as a consequence result of
the preconfining. Since the convergence readings were taken daily, the time-
dependent behaviour of the rockmass could not be identified. The finding of
these convergence plots is the result of both the geometrical change in the
excavation as the face moves away from the measuring instrument and the time-
dependent behaviour of the rock.

Although no continuous convergence data was collected by the preconfining
measurements at the test site, useful information could still be derived from
its daily convergence data. Examples of such data are shown in Figure 5.4.3, Figure
5.4.4, Figure 5.4.5, and Figure 5.4.6. The positions of the four convergence
stations relative to the preconfining face are shown in Figure 5.4.3. Time-series
in each of these figures were divided into three regions in terms of the distance
between the measuring station and the face (i.e., <20 m, 20-40 m and >40 m) and
these regions are shown by vertical hatched lines. The vertical scale bar in both
graphs shows the rate of initiation of preconfining and hence well of that scale line
indicates the convergence measured prior to preconfining in the panel. The
turn of the plot shown in the intermediate region is from installation day to the day
when the distance between the lane and the measuring station reached 20 m. In
this region all four stations showed very high convergence.
The region in the middle, between the two vertical dotted lines, (>20 m and <40 m) has two subsections, which are before and after the initiation of preconditioning. Compared to the first section (<20 m), a relatively low convergence rate is expected in this region because of the increasing distance between the face and the measuring stations.

However, it is quite clear that the measurements from all four stations show a significant increase in convergence rate just after the initiation of preconditioning. This increase is due mainly to an increase in the instantaneous response at blasting time, as well as a probable slight increase in the steady-state convergence rate. The instantaneous response was expected to be larger, as a larger stress transfer would take place because a larger volume of rock ahead of the face would be affected by preconditioning. In the rightmost section, which represents measurements taken at distances greater than 40 m from the face, all measurements decrease back to a fairly consistent level of convergence.

The measurements also show very high convergences during the seismic events in the vicinity of the stope, as shown in Figure 5.4.8. In order to correlate the convergence data with seismic data obtained from the PSS, an elastic numerical model was used to determine the elastic component of the convergence, and the inelastic components were determined by subtracting the computed elastic convergence from the convergence measured underground. The result is shown in Figure 5.4.8, where a good qualitative correlation was observed. However, attempts to quantify the correlation between the seismic event magnitudes and the convergence rate were not successful.
Figure 5.4.3 Measurements from convergence station A

Figure 5.4.4 Measurements from convergence station B
Figure 5.4.5 Measurements from convergence station C

Figure 5.4.6 Measurements from convergence station D
Figure 5.4.7 Positions of convergence stations

Figure 5.4.8 Plot of convergence measurements, showing the effect of seismicity on total convergence rate and comparison of elastic and inelastic components of total convergence
The rate of convergence is a function of many constant and variable factors, such as reef type, depth, face advance rate, geology, seismicity, fracturing, local stress field and mining configuration. Figure 5.4.9 shows a comparison of the average convergence rate between the preconditioned and unpreconditioned panels. Average convergence rates were calculated from the measurements taken from a total of 51 monitoring stations. After the initiation of preconditioning, some factors influencing the convergence rate, such as local stress field, seismicity, and face advance rate, were changed. Within 40 m of the face, a significant increase in convergence rate in preconditioned panels was noted. This increase in total convergence rate is due to both an increase in the instantaneous response at blasting time and an increase in the steady-state convergence rate. It appears then that preconditioning results in a larger mobility of the rockmass, which helps to dissipate the stored strain energy.

Figure 5.4.9 Average convergence rates of all (51) stations at the preconditioning test site
The convergence rates calculated for back areas (i.e. greater than 40 m from the face) for both preconditioned and unpreconditioned panels are the same. This supports an earlier statement that the effect of preconditioning is local (i.e. in space and time).

5.4.3 Fracturing in the stope hangingwall

Fracture mapping studies were initiated prior to the start of preconditioning and continued during the period of preconditioning. More than a thousand fractures were mapped and classified into three types, namely: faults, fissures and joints. Fractures with visible movement indicators such as gouge or slickensides were termed “faults”. “Fissures” were defined as fractures with significant dilational features, and the discontinuities with no or very minor displacement were termed “joints”. By far the most common fracture type were joints, making up 69% of the total. Faults made up about 31% of all fractures, and fissures were uncommon and made up less than 1%.

The fractures were predominantly parallel to face as shown in Figure 5.4.11(b), with a second cluster at approximately 90° to the face. The dip of the fractures was mainly at a high angle towards and away from the face, as shown in Figure 5.4.11(a). A second set dipping at an intermediate angle of approximately 40° and a third dipping away from the face at an angle of up to 30° were also observed.

Five distinct fracture groups were identified at the test site on the basis of their spatial orientation with respect to dip and strike (Grodner, 1997). These groups have been labelled Groups I to V and are shown schematically in Figure 5.4.10 and as poles-to-plane plots in Figure 5.4.11(c). Their characteristics are summarised in Table 5.4.3.

The majority of fractures mapped were face-parallel and steeply dipping (e.g. Group II). There was also a group of face-parallel, shallow-dipping fractures that dipped towards the face. These shallow-dipping fractures were restricted to the lava hangingwall and comprised Group I. Many of the shallow-dipping fractures
were actually extensional features that had developed later in the lava, sub-parallel to the pre-existing joints and had a very low persistence. Most of the steeply dipping face-parallel Group II fractures occurred predominantly at the face, and it is thought that these represented short, relatively intense, mining-induced fractures. Both the shallow-dipping and the steeply dipping fractures were predominantly face-parallel and as such they split the hangingwall up into oblong blocks of rock. It is generally found that these blocks that fall out during a seismic event.

Figure 5.4.10  Schematic view of fracture groups (not to scale)

The Group I faults and joints, which appeared to be restricted to the lava hangingwall, are thought to have formed as a result of mining-induced stress changes at or immediately in front of the face. These are face-parallel and can, in places, be linked to more steeply dipping intra-reef and footwall fractures. This would seem to indicate that the shallow-dipping Group I and steeply dipping Group II fractures might, in fact, be from the same fracture set. The different orientations would appear to be due to the different response of the various rock types to the same stress, rather than a series of different stresses producing different fracture patterns.
Figure 5.4.11  Summary of orientation data of fractures mapped prior to and after the initiation of preconditioning (after Grodner, 1997)

Note: c & f are the Schmidt Net (lower hemisphere projection) of poles to all fractures prior to and after preconditioning.
Faults and joints of Group II were generally fairly persistent and were thought to have been formed as a result of the larger-scale stresses applied to the unmined ground. The Group II joints were observed to increase in intensity towards faults. The more persistent faults and joints of Group II were probably the first-formed fractures and, as mentioned earlier, formed as a result of larger-scale stresses on bigger unmined blocks. The low persistence fractures in this group are thought to have formed at the same time as the shallow-dipping Group I fractures.

**Table 5.4.3 Summary of characteristics of major fracture types at preconditioning test site (after Grodner, 1997)**

<table>
<thead>
<tr>
<th>GROUP</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Shallow-dipping, face-parallel extensional fractures (and occasionally shears)</td>
</tr>
<tr>
<td>II</td>
<td>Steeply dipping, face-parallel extensional fractures</td>
</tr>
<tr>
<td>III</td>
<td>Steeply dipping, face-perpendicular faults and extensional fractures</td>
</tr>
<tr>
<td>IV</td>
<td>Moderately dipping (towards face) extensional fractures lying at an acute angle to the face</td>
</tr>
<tr>
<td>V</td>
<td>Moderately dipping (away from face) extensional fractures lying at an acute angle to the face</td>
</tr>
</tbody>
</table>

Group III fractures were perpendicular to the face and dipped at approximately 80°. They were not as common as the face-parallel fractures. They occurred as joints or faults filled with a white gouge of crushed quartzite. The fractures of Group III were orthogonal to those of Groups I and II. A large number of these fractures were developed in the immediate vicinity of a leg between adjacent panels. The fractures were concentrated within the first 3 m of the open end of the panel and it is thought that the mechanism that caused the Group I fractures to develop was also dominant here. Group III fractures were observed as joints and faults (often with a white crushed quartzite infill) that were more persistent than the other fractures.

The fractures of Groups IV and V were at an acute angle to the face and had an intermediate dip towards and away from the face respectively. Fractures of these
groups appeared to interconnect Group I and II fractures and, as such, they had a low persistence.

Fractures of Groups IV and V were observed at an intermediate dip between Groups I and II, and were uncommon in comparison to the other face-parallel fractures. They were identified only after a large amount of data had been collected. These fractures formed two distinct sets, dipping at approximately 100° to each other and it appeared that they had formed after the fractures of all other groups as interconnections between the shallow and steeply dipping face-parallel fractures. The lack of fault material, either as gouge or as crushed quartzite, suggests that both Group IV and Group V fractures were extensional features. It is believed that these fractures formed where Group I and II fractures were temporarily locked against each other, but owing to the lowered minor principal stress of the area, extensional features could develop.

It is believed that the fractures of Group III are the first-formed fractures, followed by the majority of Group II fractures. Some of the Group III joints (notably those that occur at the lag between panels) probably also formed at the same time as most of the Group II fractures. After this, the remainder of Group II and all of Group I fractures are thought to have developed. Finally, Group IV and V joints were developed between the other pre-existing fractures.

The fractures mapped at the preconditioning site after the initiation of preconditioning showed the same five groups identified in the stops before preconditioning was initiated. This is shown in Figure 5.4.11 (d), (e) and (f). However, the abundances of the fractures within these groups differed once preconditioning was in progress.

Following the inception of preconditioning, there was a significant increase of 25 percent in the number of steeply dipping fractures, whilst shallow-dipping fractures showed a 61 percent decrease in abundance in preconditioned areas, as shown in Figure 5.4.12 (a) and Figure 5.4.12 (b). Fractures with an intermediate dip did not show much variation in abundance between preconditioned and unpreconditioned areas. In unpreconditioned areas, fractures with an intermediate dip made up 21 percent of the total, compared to 27 percent.
in preconditioned areas. It was, therefore, deduced that, in terms of dip orientation of fractures, preconditioned stopes have more steeply dipping and less shallow-dipping fractures than unpreconditioned stopes.

Figure 5.4.12  Pie charts of orientations of fractures prior to and after preconditioning (after Grodner, 1997)

Note: shallow-dipping fractures have a dip of 0° to 30°, intermediately dipping fractures have a dip of between 30° and 60°, and steep fractures have a dip of 60° to 90°.

The strike orientation of fractures in unpreconditioned and preconditioned stopes also appeared to change. This is shown in Figure 5.4.12 (c) and Figure 5.4.12 (d). There was a decrease in the number of fractures orientated between 0° to 30° and 150° to 180° to the face. Accompanying this decrease was an increase in
the proportion of fractures orientated between 110° and 150°. However, many of the fractures mapped after the initiation of preconditioning were recorded in panels orientated approximately 40° anti-clockwise from the conventional up-dip panels, as shown in Figure 5.4.13. If the orientation of the fractures in these diagonal panels is considered relative to the face, the majority of the fractures classified in the 110° to 150° range would actually have been orientated parallel to the face. The change in mining configuration also resulted in a decrease in fractures orientated within the 30° to 70° range. Fractures orientated between 70° and 110° showed an increase in abundance in preconditioned areas, but this can again be explained in terms of mining geometry. After up-dip mining was re-established, the preconditioned panel was mined up through a zone of fracturing developed parallel to the lag that had formed between adjacent diagonal panels. This led to an increase in the abundance of fractures orientated between 70° and 110°.

![Diagram](image)

**Figure 5.4.13** Orientation of face-parallel fractures in diagonal and up-dip panels

As stated previously, the same five fracture groups were identified in both preconditioned and unpreconditioned stopes. The orientation of the various groups was very similar for the two areas and is shown in Table 5.4.4. The strike
vector azimuth of Groups II, IV and V appeared to be very different in
preconditioned and unpreconditioned stopes. But the azimuths were more or less
180° apart, meaning that the fractures in each group were orientated almost
parallel to one another. The spherical variance is the total variance of a three
dimensional data set and describes the extent to which the data differ from a
spherical model.

Here, a comparison of the different groups showed that the spherical variance
was low, especially if compared to the spherical variance obtained if all the
fractures were grouped together. In preconditioned areas, this variance was 47.4,
compared with 61.4 in unpreconditioned areas. Thus, the spherical variance of
the groups was two orders of magnitude lower than that of the entire database as
shown in Table 5.4.4. This indicates that the groupings identified were realistic.
Thus, not only were the groups well defined within preconditioned and normal
areas, but the orientations were very similar in both mining conditions.

Table 5.4.4 Summary of the characteristics of the various fracture
groups

<table>
<thead>
<tr>
<th>Group</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dip vector plunge (normal)</td>
<td>4.1°</td>
<td>84.8°</td>
<td>75.4°</td>
<td>41.4°</td>
<td>-59.6°</td>
</tr>
<tr>
<td>Dip vector plunge (preconditioned)</td>
<td>7.9°</td>
<td>65.4°</td>
<td>77.5°</td>
<td>47.2°</td>
<td>-46.3°</td>
</tr>
<tr>
<td>Strike vector azimuth (normal)</td>
<td>9.9°</td>
<td>1.7°</td>
<td>99.1°</td>
<td>14.6°</td>
<td>17.6°</td>
</tr>
<tr>
<td>Strike vector azimuth (preconditioned)</td>
<td>27.3°</td>
<td>177.6°</td>
<td>85.9°</td>
<td>175.5°</td>
<td>163.7°</td>
</tr>
<tr>
<td>Percentage (normal)</td>
<td>26</td>
<td>38</td>
<td>21</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Percentage (preconditioned)</td>
<td>15</td>
<td>47</td>
<td>24</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Spherical variance (normal)</td>
<td>0.7569</td>
<td>0.5503</td>
<td>0.2404</td>
<td>0.4848</td>
<td>0.2420</td>
</tr>
<tr>
<td>Spherical variance (preconditioned)</td>
<td>0.1237</td>
<td>0.5641</td>
<td>0.1623</td>
<td>0.2787</td>
<td>0.0442</td>
</tr>
</tbody>
</table>
As a result of preconditioning, the abundance of Group I fractures decreased. In unpreconditioned panels these joints and faults accounted for approximately 25% of the fractures, whereas in preconditioned areas they made up less than 15% of the total. There are two potential reasons for this reduced abundance. Firstly, it is possible that because preconditioning reduces the stress at the face, these stress fractures are not able to develop deep into the lava. Secondly, the preconditioning blast may weaken the contact between the reef and the lava hangingwall by shearing and/or dilation. There was evidence of shearing along both top and bottom reef contacts, with the development of centimetre-thick shear zones on the contacts. These shears usually consisted of tiny angular pieces of quartzite (up to 4 mm in diameter) surrounded by fine white crushed quartzite powder. Occasional small en-echelon faults filled with this powdery white gouge were found. A more even hangingwall, often with impressions of pebbles from the reef, further indicated that weakening had occurred, as a strong contact would produce a much more hackly surface. This weakened contact resulted in less penetration of the production blast into the hangingwall, resulting in less fracturing. As a consequence of the reduced number of these fractures, the hangingwall quality was better in preconditioned areas.

There was a significant increase in the frequency of occurrence of Group II fractures. In certain cases, the fractures had changed character from fractures with no filling in unpreconditioned areas to gouge-filled fractures where movement was evident. This suggests that preconditioning does not cause new fractures to develop in this orientation, but rather extends pre-existing fractures. The Group II fractures intersected the more shallow-dipping Group IV fractures. This was more common in preconditioned areas than in unpreconditioned areas. It appeared that preconditioning extended the pre-existing fractures and, in this case, caused them to intersect.

The Group III fractures showed almost no variation in abundance between preconditioned and normal areas. This was probably because they had formed much earlier than the other fractures observed. The stresses that caused the fracturing in this orientation were thus probably no longer dominant, which would prevent the preconditioning blast from causing further fracture growth. The majority of the fractures in this group, apart from those developed in the 3 m wide
zone parallel to the lag, showed intense shearing. This was most likely due to seismic events in the slope. However, it was difficult to determine if preconditioning had caused any further shearing.

Preconditioning does not cause the development of new fracture sets. Rather, the relative abundances of pre-existing fracture sets is modified, as shown in Figure 5.4.14. In preconditioned areas, there is better clustering of the fractures into groups. This suggests that preconditioning actually reduces the randomness of fracturing by enhancing the fractures in certain specific orientations.

![Percentage Fractures Graph](image)

**Figure 5.4.14** Graph showing relative abundance of the various fracture groups in normal and preconditioned areas

From Figure 5.4.14 it can be seen that Group I fractures showed a decrease in occurrence where preconditioning had taken place. This was most likely due to the separation of the contact between the reef and hangingwall induced by the preconditioning blast. In contrast to this, there was a definite increase in abundance of Group II fractures where preconditioning had taken place. This increased abundance was not due to the development of new fractures, but rather the extension of small pre-existing fractures as a result of preconditioning. Group IV and V fractures are thought to be formed when blocks created by Group
and II fractures lock against one another, so that the resultant compressive forces cause further fracturing. However, in preconditioned areas, it is thought that this occurs further ahead of the face.

5.4.4 Hangingwall profiles

Profiling was used to distinguish between a normal and a preconditioned hangingwall, and to examine the changes in hangingwall conditions between adjacent preconditioning holes. Numerous profiles were measured underground by stretching out a measuring tape along a particular line and then measuring the vertical distance between the tape and the hangingwall at various points along the tape. The dip of the tape and average dip of the hangingwall were recorded, as well as the position and orientation of each profile. Two types of profiles were measured underground. Initially, only the peaks and troughs in the hangingwall along various 10 m profiles were measured. Then the measurements were taken every 2 cm along a series of 5 m profiles. The mapped positions of preconditioning hole sockets and the changes in gradient and profile length of these profiles were noted. In all cases, there was a minor increase in the gradient and length with distance from the preconditioning holes, but even the roughest areas where the poorest hangingwall conditions were found between the preconditioning sockets were significantly smoother than in unpreconditioned areas. This effect is shown in Figure 5.4.15.

![Figure 5.4.15](image)

Figure 5.4.15 Variation in profile length and gradient between preconditioning holes

203
In summary, it was possible to quantify the differences in the hangingwall condition in preconditioned and unpreconditioned panels. All the methods considered showed that the hangingwall is less damaged in preconditioned panels, and that the likelihood of fall-out and dilution of the reef is reduced.

5.4.5 Stress determination

Strain measurements

Although the understanding of the mechanism of preconditioning had been refined using the findings from an intensive monitoring programme, no direct measurements of stress transfer in the fractured zone ahead of the stope face had been made. It was decided, therefore, to undertake stress determination studies ahead of an advancing face. Since the measurements would be taken in a highly stressed and fractured rockmass, the suitability of various strain measuring instruments that would work in this environment was investigated. It was found that no existing instruments could be used reliably in highly stressed and fractured rockmass. There was, therefore, a need to design a new instrument to perform these measurements.

A prototype solid inclusion cell was made in late 1995, and four cells were manufactured early in 1996. Figure 5.4.16 is a diagram of the solid inclusion cell. Prior to installation underground, one of the cells was installed in a 300 mm cubic rock specimen and the readings were calibrated under controlled loading conditions in the test laboratory shown in Figure 5.4.17. Two of these instruments were installed at about 30 m ahead of an advancing up-dip panel West 2 in the 84-49 longwall. This panel was being preconditioned at the time and the instruments were installed just above the reef plane. The objective was to undermine and then retrieve the instruments.

Strain measurements were taken daily as the face advanced towards the instruments. Figure 5.4.18 shows the results from one of eight rosettes that was orientated in a plane parallel to the face. The 0° gauge was orientated in the direction of the hole.
Figure 5.4.16  Solid inclusion cell designed to measure strain changes in fractured rock

Figure 5.4.17  Calibration of solid inclusion cell at the test laboratory

An elastic modulus of 28.5 MPa was estimated for the instrument from the laboratory tests described above and was used to produce these profiles. UDEC modelling results (Lightfoot et al., 1994) were scaled for comparison, as shown in
Figure 5.4.19. The apparent sudden relaxation of the cell in two directions is not physically possible and must, therefore, reflect a deficiency in the instrument, such as a failure of the resin used to install the instrument.

![Graph showing strain measurements](image)

**Figure 5.4.18**  The measured strains of the three strain gauges in the B90 rosette (on a plane parallel to face)

![Graph showing stress profile](image)

**Figure 5.4.19**  Stress profile ahead of an advancing face as obtained from strain measurements taken underground
Drill hole shape

Effective preconditioning should result in reduced stress near the face. It was believed that measurement of the degree of deformation in holes drilled at the face could provide some insight into the state of stress of the ground into which the drilling took place. This measure could then be used to assess the effectiveness of preconditioning.

The shapes of a number of holes in both preconditioned and unpreconditioned panels were determined by measuring the diameters both horizontally and vertically and this is shown in Table 5.4.5. Rigging holes drilled at the top of the face extended beyond production holes and were also measured after the blast. Production sockets, although less reliable as a result of direct blast damage, were measured in the same way. The ratio of horizontal to vertical measurements was used to determine the amount of deformation of any given hole. A ratio of 1 indicates a circular (undeformed) hole. The greater the ratio, the greater the degree of deformation and, thus, the higher the vertical stress acting on that hole. It is clear from the measurements that the ratios were much closer to unity (circular) in the preconditioned face than in the unpreconditioned one. This indicates that the stresses were lower in the preconditioned panel and that preconditioning was effective in transferring stress away from the area immediately ahead of the panel face.

5.4.6 Fragmentation

The model of the mechanism of preconditioning describes the process as an injection of gas generated by the blast, opening up the existing fractures within the rockmass. Since the preconditioning blast is initiated just prior to the neighbouring production blastholes, the production blast should be much more efficient in breaking the face. This was indicated by the improved advance rates achieved in the preconditioned panels at the project site and should also be seen in the improved fragmentation resulting from the production blast.
Table 5.4.5 Hole shapes in preconditioned and unpreconditioned panels

<table>
<thead>
<tr>
<th></th>
<th>Number of Holes</th>
<th>Average (Horizontal)</th>
<th>Average (Vertical)</th>
<th>Average Ratio (H/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpreconditioned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rig Holes</td>
<td>12</td>
<td>43.5 mm</td>
<td>35.4 mm</td>
<td>1.24</td>
</tr>
<tr>
<td>Production Holes</td>
<td>11</td>
<td>46.4 mm</td>
<td>33.7 mm</td>
<td>1.39</td>
</tr>
<tr>
<td>All</td>
<td>23</td>
<td>44.9 mm</td>
<td>34.6 mm</td>
<td>1.31</td>
</tr>
<tr>
<td>Preconditioned</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rig Holes</td>
<td>14</td>
<td>42.5 mm</td>
<td>38.4 mm</td>
<td>1.11</td>
</tr>
<tr>
<td>Production Holes</td>
<td>25</td>
<td>48.5 mm</td>
<td>45.3 mm</td>
<td>1.07</td>
</tr>
<tr>
<td>All</td>
<td>39</td>
<td>46.3 mm</td>
<td>42.8 mm</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Although some automated techniques of image processing of fragmented rock were available, it was also possible to use simple two-dimensional photographic images of blasted rock to quantify the differences between fragments in preconditioned and unpreconditioned panels. Photographs of preconditioned and unpreconditioned rock piles were taken at the slope face prior to cleaning. Since the contrast in a pile of broken rock was not high enough for an automated process to work efficiently, the edges of the rock fragments were traced manually. Ten photographs from each of the two panels were examined and the 10 largest fragments in each photograph were measured. The area of each fragment was calculated using a digital planimeter and the dimensions (i.e. long and short axes) were measured manually.

The averages of calculated areas of the fragments in each photograph are plotted in Figure 5.4.20. This shows that the fragment area is smaller in preconditioned panels by 50 percent compared to the fragment area in unpreconditioned panels. The lengths of the long and short axes were also less in the preconditioned panel, as shown in Figure 5.4.21. This improved fragmentation from a production blast results in smaller-sized and more rounded particles, thus improving material-handling efficiency.
Figure 5.4.20  The averaged projected areas (size) of fragments from preconditioned and unpreconditioned panels

Figure 5.4.21  The fragment size distribution in preconditioned and unpreconditioned panels

5.4.7  Ground Penetrating Radar

Ground Penetrating Radar (GPR) was used to determine the effect of preconditioning on the rockmass. The electro-magnetic pulse emitted by the GPR