Safety in Mines Research Advisory Committee

DRAFT

Final Project Report

Develop and implement preconditioning techniques to control face ejection rockbursts for safer mining in seismically hazardous areas

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Executive summary

An extensive research programme to address the issue of rockburst control has been undertaken over a number of years. Rockbursts resulting from mining-induced seismicity are a continual hazard in the deep-level gold mines of South Africa. Face bursting is one of the two primary rockburst mechanisms, involving violent slip on pre-existing fractures in the zone of fractured rock that develops ahead of mining faces.

This research report discusses the development of preconditioning techniques to control face bursts, for safer mining in seismically hazardous areas. Preconditioning involves regularly setting off carefully tailored blasts in the fractured rock immediately ahead of a mining face, so as to encourage slip on pre-existing fractures, in order not to allow the accumulation of high strain energy density in the rock mass.

Two different preconditioning techniques have been developed, namely face-perpendicular preconditioning and face-parallel preconditioning. Although the techniques were developed at different project sites, there seems to be no fundamental rock mechanics reason why either method could not be applied in any given mining environment. However, 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. Face-perpendicular preconditioning can usually be readily integrated into an existing mining cycle, without any disruption to production. Guidelines for both techniques have been compiled, based on current knowledge.

Both face-perpendicular and face-parallel preconditioning have prevented face bursting in areas to which they have been applied, even though several large seismic events have occurred close to the faces in 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.

In order to determine the optimum blast parameters for achieving the most effective preconditioning, an extensive optimisation study was carried out for the face-perpendicular preconditioning technique. While optimum values for parameters such as

hole length, diameter and spacing were determined, it was ultimately concluded that the differences in results obtained by varying the preconditioning parameters were less significant than the clear positive differences observed when comparing preconditioned areas with non-preconditioned areas.

Owing to a fundamental lack of understanding of preconditioning, certain mines have been trying to implement preconditioning under inappropriate conditions or to solve problems to which preconditioning is not suited. Therefore, there is a clear need for the formation of implementation teams that can provide assistance with respect to the implementation of preconditioning and the training of personnel at sites to which preconditioning is to be introduced.

In order to assure successful implementation of the techniques into the mining environment, a structured implementation process has been developed. The education of all production personnel and the training of the stope crew are essential. The mine's safety and training departments' personnel should also be included in the process. In addition, the inclusion of preconditioning in the mine's Code of Practice is recommended.

Preface

SIMRAC Project GAP 336 (1996 – 1997) was formulated with the intention of completing and expanding on research work conducted for SIMRAC Project GAP 030 (1993 – 1995). This report supplements the final project report for GAP 030, which should be consulted for more detail on the development of the preconditioning method.

Acknowledgements

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The work has enjoyed the co-operation of the South African gold mining industry and, in particular, that of Western Deep Levels South Mine and Libanon Gold Mine where the main research sites were situated. The team would like to thank the management of both mines 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 who have given us much needed assistance during the course of our field experiments. Without the help of the people on the mines, none of this work would have been possible.

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Glossary of abbreviations, symbols and terms

Abbreviations

Ammonium Nitrate + Fuel Oil	ANFO
Blyvooruitzicht Gold Mine	BGM
Chamber of Mines Research Organisation	COMRO
Council for Scientific Industrial Research	CSIR
CSIR: Mining Technology	Miningtek
Data Acquisition Unit	DAU
East Rand Proprietary Mines	ERPM
Ground Penetrating Radar	GPR
Libanon Gold Mine	LGM
Portable Seismic System	PSS
Safety In Mines Research Advisory Committee	SIMRAC
Ventersdorp Contact Reef	VCR
Western Deep Levels	WDL
Western Deep Levels South Mine	WDLS

Symbols

Major principal stress	σ_1
Intermediate principal stress	σ_2
Minor principal stress	σ_3
Magnitude of a seismic event	M
Minimum magnitude	M_{min}
Seismic moment	M_0
Material density	ρ
Source-receiver distance	R
Peak particle velocity	v_{max}
Peak particle acceleration	a
Seismic attenuation factor	κ
Static stress drop	τ_S

Terms

Rockburst

Damage to an underground mining excavation caused by brief violent movements of the rock mass in response to a seismic event.

Face burst

A type of rockburst caused by the accumulation of strain energy in the fractured rock mass ahead of a mining face; characterised by the violent ejection of material from the face into the excavation.

Preconditioning

A method which makes use of explosives ahead of mining faces to control and limit the amount of damage resulting from face bursts.

1 Introduction

1.1 Research problem

According to the accident database compiled by Miningtek under SIMRAC project GAP 330, a total of 214 fatalities resulted from 134 face burst incidents throughout the South African gold mining industry during the past seven years (Table 1-1). This represents 30 per cent of the total of 719 rockburst fatalities (which is 43 per cent of a total of 1 654 rock related fatalities). Thus, face bursting is a major concern for the industry. The most problematic areas currently are on the VCR and Carbon Leader reefs, which are responsible for more than half of all face burst fatalities.

Table 1-1: Statistics of rockburst fatalities in South African gold mines from 1990 to 1996.

	Face Burst (only)		Rockburst (all)	
Reef Type	No. of Fatalities	No. of Incidents	No. of Fatalities	No. of Incidents
Basal	10	4	48	25
Carbon Leader	52	27	190	100
Composite	11	7	17	12
Main	4	4	16	14
Vaal Reef	20	14	74	40
Ventersdorp Contact	79	51	222	140
Others / not specified	20	12	67	45
Off reef	18	15	85	48
Total	214	134	719	424

1.2 Objectives and aims of this study

1.2.1 Main objective

The main objective of this project is to develop and implement preconditioning techniques to control face ejection rockbursts for safer mining in seismically hazardous areas.

1.2.2 Goals

The primary output from this project is the development of two preconditioning techniques (i.e. face-parallel and face-perpendicular), which can be implemented successfully into mining layouts and mining cycles, to reduce the incidence and effects of damaging seismic events on highly stressed stope faces. These techniques will be used by mines experiencing face bursting while mining at deep levels or undertaking remnant extraction of potentially highly stressed pillars. The successful implementation of these techniques will allow the safe mining of remnants and faces that are currently dangerous to mine, due to the incidence of face bursting.

1.3 Research design

SIMRAC Project GAP 336 was designed as a continuation of an earlier SIMRAC project, GAP 030, during which conceptual models of face bursting and preconditioning were developed and verified, through numerical modelling and experimentation at field sites. Field work for the development of face-parallel preconditioning took place at the 17-24W pillar on Blyvooruitzicht Gold Mine (BGM), while field work for face-perpendicular preconditioning took place at the 87-49W longwall on Western Deep Levels South Mine (WDLS). The BGM 17-24W site had been in operation prior to the start of Project GAP 030 and field work continued there throughout the course of that project, while field work had been conducted at WDLS 87-49W only since May 1995. Thus, the face-parallel preconditioning technique was at a relatively advanced stage of development at the end of Project GAP 030, while the face-perpendicular technique was in need of further development.

The work at both field sites was to be continued during the course of Project GAP 336, so that both preconditioning techniques could be more fully developed. Certain issues, relating to the fundamental mechanism of preconditioning and to the design of the face-parallel preconditioning technique, which remained unresolved at the end of Project GAP 030, would also be more adequately investigated. In addition, it was recognised that there was a need for the knowledge and experience gained with respect to preconditioning, during the course of both Project GAP 030 and GAP 336, to be transferred to the mining industry for implementation, after the completion of the research work. Thus, a major focus of Project GAP 336 was on developing guidelines for the implementation of both preconditioning techniques and determining the requirements for the successful implementation of preconditioning in the industry.

2 Literature evaluation

2.1 Development of preconditioning

Preconditioning, or "destressing" as it was initially called, was first introduced as a means of ameliorating rockburst conditions in deep mines by the management of the East Rand Proprietary Mines (ERPM) in the early 1950's with the co-operation and guidance of the CSIR (Roux et al, 1957). The principle on which destressing was based at that time was that *"The occurrence of rockbursts might be reduced or their violence decreased by increasing the depth of the fracture zone at the face of the working stope"*. The argument for this was based on the concept that, if the holes drilled at right angles into the face were blasted, they would advance the depth of fracturing and in so doing transfer the high stress zone further away from the face into the solid. Furthermore, should sudden failure occur in the high stress zone, only limited damage would result, because of the cushion effect of the 'destressed' zone ahead of the face.

Field trials were carried out by ERPM in the 1950's to assess the feasibility of destressing, or preconditioning, as a safety measure to reduce the incidence of rockbursts. The results of these trials were encouraging. For example, the incidence of rockbursts per area mined was reduced by 36 per cent; the number of severe rockbursts was reduced by 73 per cent, and the frequency of on-shift rockbursts dropped to almost zero. However, despite these apparent benefits, preconditioning was not generally accepted by mines as a viable and safe mining method. To address this problem, the Chamber of Mines Research Organisation (COMRO) initiated a programme to re-investigate preconditioning as a viable, safe mining method in the late 1980's.

COMRO's involvement in preconditioning began in 1987 with experimentation at West Driefontein Gold Mine, where the 32-12W stope was being mined into a large remnant along the Western Deep Levels (WDL) boundary (Rorke et al, 1988). The technique being implemented made use of long, face-parallel holes drilled along the length of the 30 m panels. The 76 mm diameter holes were positioned between 2,5 m and 3,5 m ahead of the face and drilled within a shift. The panels mined beyond the line of the previous preconditioning holes and, hence, the spacing between preconditioning holes averaged about 8 m.

Following a trial period of five months of test drilling, preconditioning was implemented in two panels. Once the technique had been optimised, all five panels within the stope were preconditioned. A total of 18 preconditioning blasts were taken in the 11 month period of the project. Convergence of 5 mm to 40 mm associated with a preconditioning blast, face scaling of up to 300 mm, and a lack of damage at the face following large seismic events were reported. An observed reduction in low-angle fracturing compared to non-preconditioned panels resulted in improved hangingwall stability, which may partly account for the lack of seismic damage. However, the project was terminated when the technique could not be integrated into a new layout, which was required as the stope was approaching a seismically hazardous structure.

Preconditioning was then initiated on Blyvooruitzicht Gold Mine (BGM) in the 18-13W stope, an up-dip panel along a protection pillar adjacent to a seismically active fault (Rorke et al, 1990). A series of 30 m long, 76 mm diameter holes fanned out from the dip gullies were planned to be drilled into the entire pillar, with the intention of "preconditioning" the pillar with one blast. Eventually, only the holes on the edge of the pillar could be drilled to nearly their full length. The other holes were drilled to only 10 m. Difficulties experienced with drilling into the core of the pillar provided some insight regarding the condition of the pillar. Despite the seismicity from the adjacent fault, the pillar was eventually mined out without incident by fanning the preconditioning holes drilled from the up-dip gullies at five different face positions. Improved hangingwall stability was reported to be due to steeper extension fractures following the introduction of preconditioning.

Extraction of a dip pillar with preconditioning at BGM began in mid-1990 (Lightfoot et al, 1996). The 30-24W stope is situated at the southern extent of BGM near the boundary pillar to Western Deep Levels (WDL). This dip pillar was 40 m wide and 150 m long with the top of the pillar terminating on a stabilising pillar. Initially, the pillar was being conventionally mined but, after problems with consistently poor ground and several large seismic events, the mine decided to implement their own preconditioning project in mid-1990. They requested that COMRO monitor this project. The method of preconditioning was similar to that used at the 18-13W stope: 10 m long holes fanned out from the dip gullies. Difficulties with drilling and frequent damage to support and the collar area of the holes all resulted in production delays.

Problems also arose due to the mining by WDL of two large longwalls just to the south of the boundary pillar. The stress changes induced in the preconditioning stope resulted in a significant increase in seismicity levels. A large rockburst in October 1991 resulted in several fatalities. This prompted a change in the preconditioning layout to face-parallel drilling. However, before any progress could be made with this technique, the stope had to be abandoned in early 1992, due to increasing seismicity levels.

Work on 17-24W stability pillar site at BGM began in April 1990, using preconditioning holes that were fanned out sub-perpendicular to the stope face. The intention was to extract a long strike pillar using preconditioning to reduce the risk of rockbursts at the face. Initially, the mining was in an up-dip direction. However, in an attempt to improve the effectiveness of preconditioning, the panels were changed to breast in September 1992. This new layout allowed for the drilling of face-parallel preconditioning holes. On the whole, this mining geometry proved to be more successful for preconditioning. The report entitled *"The implementation of preconditioning as a rockburst control technique"* (Kullmann, 1996) reflects the state of knowledge regarding the implementation of face-parallel preconditioning at this site.

In late 1994, it was recognised that, although face-parallel preconditioning appeared to be well suited to the mining of long and narrow strike pillars, it would be difficult to implement in a normal deep-level longwall production environment without imposing considerable delays in the mining cycle. For this reason, a new experimental site was opened on a deep-level longwall on WDL South Mine. Experiments were undertaken at this site which involved drilling short face-perpendicular preconditioning holes as a standard addition to every production blast. The experiments indicated that it is possible to implement this method in a deep-level longwall mining environment without significant disruption to the mining cycle. The initial findings from this experiment were discussed in the SIMRAC project GAP 030 final report, entitled *"Preconditioning to reduce the incidence of face bursts in highly stressed faces"* (Lightfoot et al, 1996).

2.2 Preconditioning mechanism

Pioneering work conducted by other researchers in the field of blast-induced fracturing was reviewed by Daehnke (1997). Kutter (1967) and Kutter and Fairhurst (1971) studied the fracture process of an underground explosion in rock. It was found that the main role of the explosively generated stress wave is to create a dense zone of radial fractures around the borehole, which is in turn surrounded by a ring of wider spaced radial cracks. The gas pressure subsequently exerted against the walls of the highly fractured cavity generates a quasi-static stress field which induces further extension of the radial cracks. The high-pressure gases were found to play a more important role than had been anticipated, but the gas pressure on its own would not have been very effective: the pre-cracking and effective widening of the cavity by the emitted stress wave facilitated the active engagement of the expanding gases in rock fragmentation. Significantly, Kutter and Fairhurst (1971) also established that, at high loading rates, the fracture pattern in a material such as Plexiglas is practically identical to that in hard rock without joints.

The work carried out by Dally et al (1975) using dynamic photoelasticity and transparent materials served to confirm the importance of gas pressurisation as a fracture driving mechanism. It was found that considerably longer cracks resulted when combustion gases were confined within the borehole, rather than being allowed to vent to the surroundings from the hole collar. Calculations performed by McHugh (1983) indicated that gas pressure could increase crack lengths considerably. Explosive residue was detected on blast-induced fracture surfaces after laboratory experiments, demonstrating that combustion gases had penetrated to the tips of the cracks.

On the basis of fracture mechanics, Ouchterlony (1974) determined that the critical gas pressure for crack growth increases with an increasing number of cracks and that the influence of the circular borehole on the crack-tip stresses does not extend beyond a near-zone of two to three hole radii. It was also found that the crack lengths obtained in rock blasting are strongly influenced by the extent of gas penetration into the fractures. A description of gas flow, based on work conducted by Nilson (1981, 1986), was incorporated into a boundary element program by Schatz et al (1987). The output from the modelling of gas-driven fracture propagation in a pre-stressed medium correlated favourably with post-blast observations of laboratory tests. It was found that fracture length is ultimately controlled by gas volume loss, leakage to the adjacent rock mass and thermal quenching.

3 Research methodology

The major enabling outputs of the project and the methodology used to accomplish these outputs are summarised in this section.

3.1 Preconditioning mechanism

One of the conclusions stated in the SIMRAC Project GAP 030 Final Project Report (Lightfoot et al, 1996) was that *"The mechanism of preconditioning does not involve the prolific generation of new fractures but, rather, involves slip on existing fractures"* and that *"Whether the cause of this slip is a change in the local effective stress as a result of the injection of gases into the fractures or the dynamic shake-up of the local rock mass as a whole is not clear at this stage."* The recommendation made in that report was: *"In order to assure the successful implementation of preconditioning in the mining industry as a whole the following issues must still be addressed: Ascertain the actual mechanism of preconditioning. This is an important aspect for explosive design, both the chemical content and the emplacement."* One of the goals of SIMRAC Project GAP 336 was to address this shortcoming in the understanding of the preconditioning method.

3.2 Rock mass response to preconditioning

Recently, progress was made in another SIMRAC project (GAP 332) towards understanding the continuous time-dependent convergence behaviour of tabular excavations and the possible use of these measurements to identify areas prone to face bursting (and therefore in need of preconditioning). The reader is referred to Malan (1998) and the December 1997 progress report of project GAP 332 for a detailed explanation. It should be clearly noted that, during the time of writing of this report, the use of these continuous measurements was still under investigation and these preliminary results should, therefore, be treated with caution. However, the potential usefulness of continuous convergence measurements in relation to preconditioning warrants a brief discussion in this report.

3.3 Enabling output 1: Guidelines for the implementation of face-parallel preconditioning

Develop guidelines for the implementation of long, large-diameter, face-parallel holes for preconditioning stope faces as a tool for safe mining of remnant pillars at depths between 1 000 m and 3 000 m.

- *Carry out ongoing monitoring using all relevant monitoring techniques at a remnant pillar preconditioning site.*
- *Analyse the data in terms of the most recent understanding of face-parallel preconditioning.*
- *Adapt/modify the conceptual model of preconditioning. Test the model against the available data using numerical simulation programs.*
- *Finalise existing guidelines for the implementation of preconditioning to reflect the current understanding.*

The method of face-parallel preconditioning has been under investigation since the late 1980's, when the project began at West Driefontein. Considerable experimentation was conducted into the drilling and blasting of the large-diameter, face-parallel holes. However, a minimum of instrumentation was used at that site to investigate the effects of preconditioning and, therefore, it was not possible to quantify the benefits of preconditioning.

3.3.1 Blyvooruitzicht Gold Mine

Extraction of the 17-24W stability pillar at Blyvooruitzicht Gold Mine (BGM) began in April 1990. After experimenting with alternative methods of integration of preconditioning into the production requirements, a method of face-parallel preconditioning was combined with an overhand mining configuration. From September 1992, this layout remained consistent and intense monitoring was carried out at the site, resulting in the formation of a database comprising information from more than three years of mining.

Although the BGM site provided great insight into rock mass behaviour near a stope face and into how this behaviour is affected by preconditioning, the knowledge gained was from only one site under very specific conditions. Since mining of the pillar took place only with preconditioning, it is difficult to know how much benefit was actually gained by those blasts, as the extent to which the faces would have experienced face bursting without preconditioning is unknown (it is thought that the conditions would have been more severe in the absence of preconditioning). It was, therefore, decided that another research site should be sought in order to compare the results of face-parallel preconditioning at that site with the results from BGM.

3.3.2 Libanon Gold Mine

It is expected that the face-parallel preconditioning experiment currently being set up at Libanon Gold Mine (LGM) will contribute much valuable additional insight into the mechanisms and suitability of this method of preconditioning. Libanon Gold Mine has many stability pillars on the VCR and some of this ground is currently being mined, due to its high grade. However, before this ground can be safely accessed, it is being undermined by large-scale mining of the low-grade Kloof Reef, which is generally uneconomical on its own. Therefore, it was suggested that preconditioning be investigated as a technique to provide a safer mining environment without the need for 'waste mining'. The 25-55W pillar was chosen as the project site at which to introduce preconditioning to the mine. Should the preconditioning technique be shown to be viable, the mine will begin work on other pillars. This project was initially funded by SIMRAC but, since the beginning of 1997, it has been separately funded by Gold Fields.

3.3.3 The use of stemming with face-parallel preconditioning

One of the conclusions stated in the SIMRAC Project GAP 030 Final Project Report (Lightfoot et al, 1996) was that *"Current methods of tamping the preconditioning holes are not ideal."* The recommendation made in that report was: *"In order to assure the successful implementation of preconditioning in the mining industry as a whole the following issues must still be addressed: Improve the tamping system. The current tamping system may result in detrimental loading of the rock mass adjacent to the stemmed portions of the preconditioning hole. This situation must be rectified."* One of the goals of SIMRAC Project GAP 336 was to address this shortcoming in the design of the preconditioning method.

3.4 Enabling output 2: Guidelines for the implementation of face-perpendicular preconditioning

Develop guidelines for the implementation of short, small-diameter, face-perpendicular holes for preconditioning of production stope faces on ultra-deep longwalls.

- *Continue to collect data relevant to the face-perpendicular preconditioning experiment from the implementation sites.*
- *Analyse the data in terms of the most recent understanding of face-perpendicular preconditioning.*
- *Adapt/modify the conceptual model of preconditioning. Test the model against the available data using numerical simulation programs.*
- *Finalise existing guidelines for the implementation of preconditioning to reflect the current understanding.*

3.4.1 Western Deep Levels South Mine

A large data set, comprising information on many aspects of the rock mass response to mining and preconditioning, was compiled during the monitoring of the introduction of face-perpendicular preconditioning to the Western Deep Levels South Mine (WDLS) 87-49W stope. This data set comprises seismic measurements, convergence-ride measurements, fracture mapping information and hangingwall profiling information, amongst others. Much valuable understanding of the rock mass response and confirmation of the effectiveness of preconditioning were gained during analysis and interpretation of the data.

An investigation into the use of short, face-perpendicular holes to precondition stope faces began on WDLS at the 87-49W longwall in May 1995. At that time, several panels were being mined up dip, with short face lengths and generally considerable leads between panels (>10 m). Preconditioning provided excellent results in terms of a reduction in seismic damage, elimination of face bursting, improved hangingwall conditions and better face advance.

At one stage, the stoping orientation was changed to diagonal mining. The face lengths increased, leads between panels decreased and the resulting overall stope face became oriented nearly parallel to a pre-existing joint set. This resulted in poor hangingwall conditions, with increased susceptibility to seismic damage. Several rockbursts occurred, as irregularly shaped pillars were being formed when the diagonal panels mined out along the stability pillar at the top of the stope.

Since reverting back to up-dip mining, ground conditions have improved significantly and the reorientation of faces has allowed for further analysis of preconditioning, as well as an optimisation study. The regular mining configuration lent itself much more readily to the assessment of the effectiveness of preconditioning.

The completion of the optimisation study at WDLS 87-49W in February 1997 marked the end of the field work associated with the preconditioning experiment at the site. Unfortunately, although the results of the preconditioning experiment were initially received enthusiastically by concerned personnel on the mine, preconditioning was discontinued at WDLS after the cessation of the project work on the mine. The main difficulty appears to be related to the lack of bonus payments for the drilling of preconditioning holes, which is perceived as extra work by the face crews.

3.5 Enabling output 3: The feasibility of forming an implementation team

Investigate the feasibility of forming an implementation team that can provide assistance with respect to implementation of preconditioning and training of personnel on individual mines.

- *Assess the applicability of preconditioning as an implementable production technique.*
- *Identify what knowledge must be transferred to industry for the successful implementation of preconditioning.*
- *Identify how best to enable this knowledge transfer.*
- *Identify the structure of a team required to transfer knowledge and implement the preconditioning technique successfully.*
- *Appoint the implementation team.*
- *Identify potential implementation sites in the industry.*
- *Initiate field trials on suitable mines.*
- *Conduct regular audits to ensure the proper implementation of preconditioning.*

Much has been learned from a study of the history 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. The favourable results that have been obtained by means of preconditioning in the past have not, on their own, been enough to bring about the widespread utilisation of preconditioning as routine practice in face burst-prone mining areas. At one mine, a lack of education of the workforce and of follow-up to the initial experimental work resulted in the abandonment of a promising rockburst control technique. These components – education and training of the workforce, and follow-up action from management – have proven to be vital factors in implementation efforts on various mines.

The training needs of the underground personnel who are responsible for the correct implementation of preconditioning have been investigated. Schuitema Associates specialise in human resource-management and they have assisted in the interviewing of mining personnel to assess their attitudes towards safety in seismically active areas and the role of preconditioning in improving safety, and to evaluate their views on methods of training in order to facilitate the effective implementation of preconditioning on the mines. The survey conducted at the project site, after the preconditioning experiment had been in place for some time (with the drill operators receiving an incentive bonus for drilling the preconditioning holes, due to complications introduced by their involvement in an optimisation experiment), revealed a prevailing attitude which later contributed to the demise of the application of preconditioning on the mine. While the workers acknowledged the improvement in underground conditions since the introduction of preconditioning, they were unwilling to do the preconditioning without extra pay for their efforts. The results from this exercise have formed an integral part of the process of knowledge transfer to the mining industry.

When the most recent findings and the current understanding of preconditioning were communicated to the mining industry via a number of seminars during 1997, a considerable amount of interest and a positive attitude were shown in response. Consequently, several mines have started or will start preconditioning under various conditions. Miningtek 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. The preconditioning research team was involved in implementation on various mines, in order to learn more about the feasibility of providing an implementation team as well as the other issues associated with the process.

4 Results

4.1 Preconditioning mechanism

The development of a conceptual model of the rock mass surrounding a deep-level stope was based on many years of detailed mapping of mining-induced fractures. Of prime significance in this model is that the rock surrounding the stope has failed prior to its excavation. Depending on mining geometry and stress conditions, these fractures can develop many metres ahead of an advancing stope face. The fractured rock mass ahead of the stope face is subjected to extremely high stresses, resulting in the complex fracture patterns observed underground. Once the fractures have been created, stress can continue to increase as long as confinement is maintained. Slip on the fractures results in the deformation of the rock mass and convergence of the hangingwall and footwall.

It seems that both slip and the inhibition of slip along the abundant fractures immediately ahead of the face could account for the complex rock mass behaviour that is observed in and around stopes underground. Owing to this complex geometry, if slip along fractures is inhibited, strain energy will be allowed to accumulate at various positions in the rock mass. This energy can be relieved when the confinement at the face is reduced by the advance of that face. If sufficient energy was present immediately ahead of the face, the resulting energy release could take the form of a face burst.

The stress fields and gas pressures generated by preconditioning blasts remobilize the blocks defined by mining-induced fractures, by shearing through asperities that are responsible for the 'lock-ups' on the fractures. In the process, strain energy release is facilitated by stable sliding of blocks past each other, thus reducing the risk of occurrence of face bursting during the production shift. Preconditioning results in the redistribution of stress away from the working face (Figure 4-1), thus reducing the risk of a face burst. The resulting less stressed ground is then also less prone to allow sudden slip on asperities when excited by incoming stress waves from distant events. In this way, it may be possible to control the size and timing of seismic events at the face, and to influence the extent and severity of damage that may occur as a result of distant events.

Since it is only the state of stress that has changed (rather than the rock mass being physically 'softened'), it is likely that, if the confinement were to be re-established in a previously preconditioned zone, the preconditioning effect could be reversed. It has been

place within a non-uniform material such as rock and particularly when considering the underground environment.

shown, both by underground observation and by computer simulation, that this is possible. Under certain circumstances, it is possible that stress can be transferred back towards the face area. This could happen either through the effects of large seismic events near the face or of poorly positioned preconditioning holes, or through the regeneration of lock-ups due to time-dependent deformation of the rock mass.

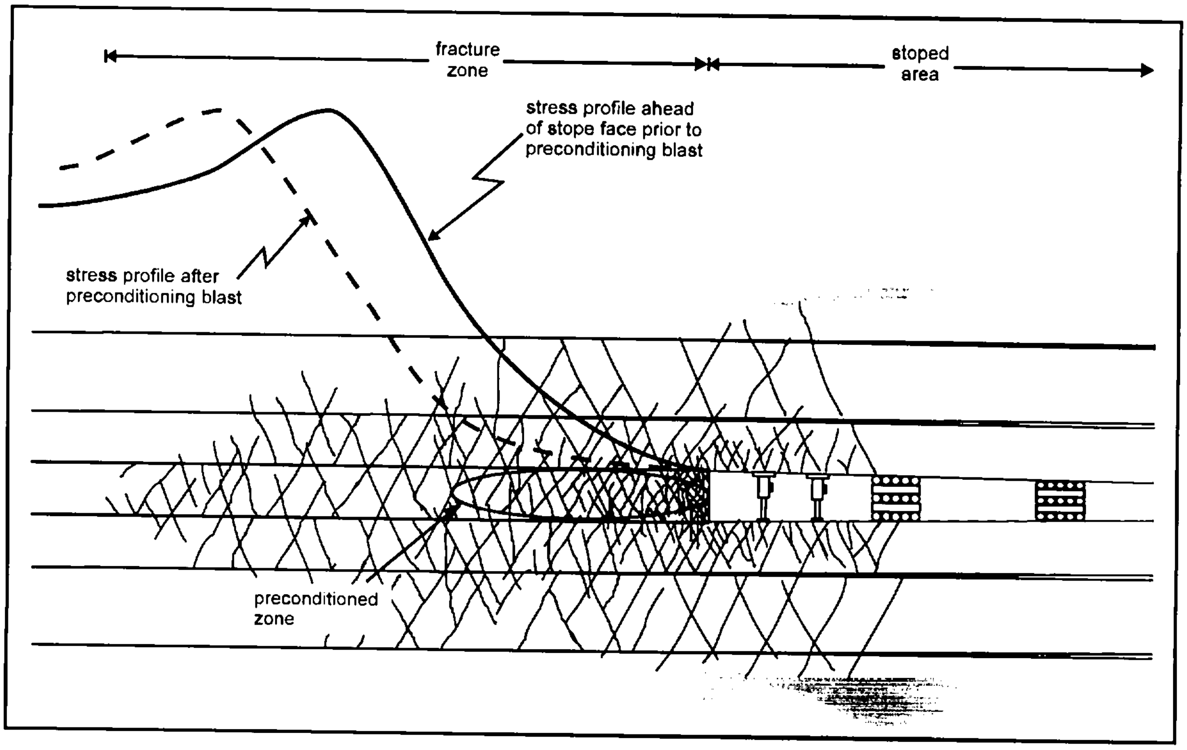


Figure 4-1: Stress redistribution due to preconditioning.

4.1.1 Influence of stress waves and gas pressurisation

As stated by Daehnke (1997), the interaction between a rock mass and detonating explosives is a complicated process which involves non-linear material behaviour, dynamic fracturing and gas dynamics in the form of hot combustion gases streaming into propagating fractures. These processes take place in a very short time interval: the detonation of the explosive and full borehole pressurisation are effected within a few milliseconds and the subsequent development of radial fractures due to gas pressurisation is completed within a few hundred milliseconds. Clearly, it is difficult to assess such complicated short-term processes quantitatively, especially when they take place within a non-uniform material such as rock and particularly when considering the underground environment.

Daehnke (1997) investigated stress wave- and gas pressure-induced fracturing in transparent material (PMMA) using high-speed photography, by means of which the spatial evolution of the stress waves and blast-induced fractures at discrete time intervals could be studied. While this work was focused on gaining understanding of the mechanisms by which blast-induced fractures are formed and propagated in rock, it also offered some valuable insight into the probable mechanism by which a preconditioning blast in pre-fractured material might achieve its effect.

4.1.1.1 Blast-induced fracturing

A summary of the results of the work described by Daehnke (1997) is presented below. Special attention has been given to those aspects which might illuminate the processes at work during a preconditioning blast. For a more detailed discussion, the reader is referred to that publication, as well as to the December 1997 progress report of SIMRAC Project GAP 332.

The detonation of an explosive charge in a borehole liberates combustion gases, which expand and suddenly pressurise the borehole cavity. The immediate vicinity of the borehole is then highly strained and borehole breakdown can result. This involves non-linear material behaviour, including fracture initiation. The rapid borehole pressurisation gives rise to stress waves which propagate into the surrounding medium. The nature of these stress waves is governed largely by the charge geometry.

Column charges do not detonate instantaneously in practice. Instead, the detonation front proceeds at a finite speed – the velocity of detonation (VOD) – along the charge length. At a VOD of less than or equal to the P-wave speed in the material (but greater than the S-wave speed), a substantial proportion of the total energy is present in the form of S-wave energy. Owing to the high VOD (between 2 000 and 6 000 m/s) of most commercial explosives, the borehole is rapidly pressurised, after which the pressure decay takes place comparatively slowly, due to the additional volume formed by fracturing and due to thermal quenching.

Immediately after detonation, radial fractures driven by tensile tangential stresses can realistically be assumed to propagate at a maximum velocity of about half of the Rayleigh wave speed of the material. This initial fracture speed rapidly decreases to less than 10 per cent of the P-wave speed, so that borehole de-pressurisation occurs at a comparatively slow rate. It has been found that the borehole pressure decay rate has a limited influence on the dynamic stress field, but that prolonged pressure decay has important implications in terms of the static stress field and results in more extensive gas-driven fracturing.

The initial amplitudes of the stress waves (typically, hundreds of MPa) are rapidly attenuated as the waves expand away from the borehole, so that fragmentation due to the stress waves is usually limited to the immediate vicinity of the borehole. The dynamic tensile stresses act for a comparatively short time before converging to the quasi-static stresses induced by borehole pressurisation, which are then responsible for the majority of the dense network of radial fractures surrounding the borehole. The stress waves rapidly outpace the fractures, which propagate at a much slower rate, so that the fractures extend mainly due to pressurisation by the combustion gases rather than under the influence of the stress waves. Interestingly, Daehnke saw no evidence of significant fracture deflection due to multiple stress wave reflections within the PMMA blocks.

Post-blast observations of the near-borehole zone typically reveal a narrow annular region of crushed rock, which has failed due to the high radial and tangential compressive stresses acting in the vicinity of the borehole wall. Beyond the region of crushed rock, a dense system of radial and circumferential cracks extends for about 3,5 hole radii from the borehole centre. The radial cracks form due to tangential tensile stresses induced by the quasi-static borehole pressurisation superimposed by tensile stresses associated with the trailing tail of the tangential stress pulse component, while the circumferential cracks form due to the very high stress gradient associated with the rapid transition from compression to tension induced by the radial stress pulse. It is only within this zone that cracks remain open after blasting. Two intermediate zones are formed outside this zone by the extension and kinking of the radial cracks which formed in the innermost zone, while, in the outermost elastic zone, the comparatively few cracks are driven by pressurisation by the combustion gases. The specific borehole cracking pattern strongly depends on the blasting condition and configuration, and on the degree of coupling between the charge and the borehole wall (increased damage is produced by increased coupling).

Daehnke considered the case of a free surface intersecting the borehole. It was found that, upon reflection of the conical S-wave front at the free surface, the material is subjected to high stresses at the reflection point. For the case of a VOD between the P- and S-wave speeds in the material, the dynamic tensile stresses acting in the vicinity of the reflection point are likely to initiate fracturing along the free surface. For the case of a stemmed charge intersecting a plane of weakness orthogonally, Daehnke found that, when gas-driven fractures intersect the plane, gaseous detonation products enter the plane and the sides of the interface separate due to the gas pressurisation. During the initial stages, when the fractures are propagating rapidly due to high stress wave and gas pressure loading, the main fractures appear to continue propagating without change in direction across the interface. As the gases driving the fractures penetrate the interface and the gas pressure separates the sides of the plane, all subsequent fractures terminate abruptly at the interface. At later times, the interface de-lamination and radial fracture propagation outwards from the borehole occur at the same rate.

A quasi-static treatment of stresses and rock displacements is generally considered appropriate for explosively induced gas-driven fractures, as most of the stress waves occur on a very brief time scale compared with that of the late-time gas fracturing phenomena. Also, the speed of the gas-driven fractures is small in comparison with wave speeds in rock, so that the gross features of the surrounding stress field are nearly quasi-static: the effect of the blast-induced stress waves on the fracturing is separated in time from the gas-driven fracturing. Daehnke used a combined analytical/numerical procedure to simulate the gas-driven fracturing associated with column blasting in competent rock confined by uniform compressive stresses; no attempt was made to model the gas leak-off as pressurised cracks interact with pre-existing voids.

During the reaction of the explosive, the detonation front pressure (acting in a localised area for a very short time) is of the order of GPa's. Owing to the effects of charge de-coupling and borehole expansion and fracturing, the actual borehole pressure driving the fractures is orders of magnitude lower than the pressure at the detonation front. In reality, gas flow is not isothermal, and convective and conductive heat transfer from the hot combustion gases to the fracture walls and into the surrounding bulk material reduces the gas energy. In addition, with increasing gas seepage into the exposed fracture walls due to rock permeability and porosity, the final fracture length decreases; for highly pre-fissured rock, this is likely to be the main mechanism restricting fracture growth.

4.1.1.2 Application to preconditioning

Clearly, the results of investigations into the mechanisms of blast-induced fracturing conducted in a homogeneous material under controlled laboratory conditions cannot be directly applied to explain the mechanism by which a preconditioning blast in a pre-fractured rock mass achieves its effect. However, the improved understanding of the interaction between stress waves, gas pressurisation and the fracturing host material gained by Daehnke (1997) and other workers in related fields can be extrapolated to derive a likely scenario for the processes active during such a preconditioning blast, as outlined below.

When the preconditioning blast is set off, the borehole is rapidly pressurised and the rock in the immediate vicinity of the borehole is pulverised due to the action of the high compressive stresses on the borehole wall. The stress waves generated by the borehole pressurisation are initially of sufficient magnitude to produce a zone of intense radial fracturing close to the borehole. The stress waves then propagate outwards and their amplitudes are reduced by the effects of geometric and intrinsic attenuation. Thereafter, the blast gases act to extend the fractures outwards from the borehole wall into the surrounding rock mass.

When the propagating fractures intersect pre-existing fractures in the surrounding rock mass, the blast gases enter the existing fractures and pressurise them. The sides of the fractures are forced apart, reducing any clamping stresses and allowing the rock to slip across the fractures in response to the prevailing mining-induced stresses acting on them, thus relieving the stress acting on the stope face as a whole. The diversion of blast gases into existing fractures reduces the number and size of new fractures, compared with what might have resulted from a blast in previously unfractured rock.

The action of the stress waves in the pre-fractured rock mass depends on the type of stress wave (whether longitudinal or shear) and on the orientation of the pre-existing fractures with respect to the direction of propagation of the stress waves. The stress waves, by introducing rapid fluctuations in time of clamping or tensile stresses, might therefore act either to increase the clamping across locked fractures, or might add to any stress tending to cause slip on the fractures, perhaps overcoming the clamping and allowing slip to take place. The local stress concentrations formed by reflections of stress waves at discontinuities in the rock mass are likely to contribute to the action of the propagating stress waves in the rock mass, as well.

While the effects of stress wave-induced remobilization of fractures can probably not be divorced from remobilization under the influence of pressurisation of blast gases in practice, it would seem that the role of the blast gases in achieving the preconditioning effect is very significant. Given that gas pressurisation has been shown to be the more important mechanism driving fracture growth at some distance from the blast in unfractured rock, it is likely that it is also the more important factor in terms of the remobilization of existing fractures.

4.2 Rock mass response to preconditioning

Deformation of the rock mass ahead of a stope face occurs in response to external influences, such as seismicity, face advance, preconditioning and time-dependent effects. It is thought that the changes experienced in the rock mass are reflected in the ground behaviour within the stope, recorded in the measurements from convergence/ride stations.

Investigations into the time-dependent deformation of the rock mass have been conducted under the auspices of SIMRAC project GAP 332 (Napier and Malan, 1997). This has led to the development of a viscoplastic displacement discontinuity model to simulate the observed deformations of the rock mass. This time-dependent behaviour is obtained through the generation of new fractures and the remobilization and extension of existing fractures.

As the stope face is advanced through the removal of rock by blasting, the fractured rock mass immediately ahead of the face experiences a sudden increase in stress. The discontinuities that are subjected to excessive stress remobilize in some time-dependent manner, resulting in a stress transfer. The extension of existing fractures and the formation of new ones all accompany this process. If this deformation of the fracture zone (and stress transfer) results in the micro-seismicity recorded following a face blast, then the two must be comparable. Malan found that there exists a good correlation between the cumulative fracture length in the numerical model and the cumulative number of seismic events following a face blast at the BGM 17-24W preconditioning site (Figure 4-

2). It was also noted that preconditioning blasts exhibited a similar decay in seismicity to the face blast, even though there was no change in stope geometry.

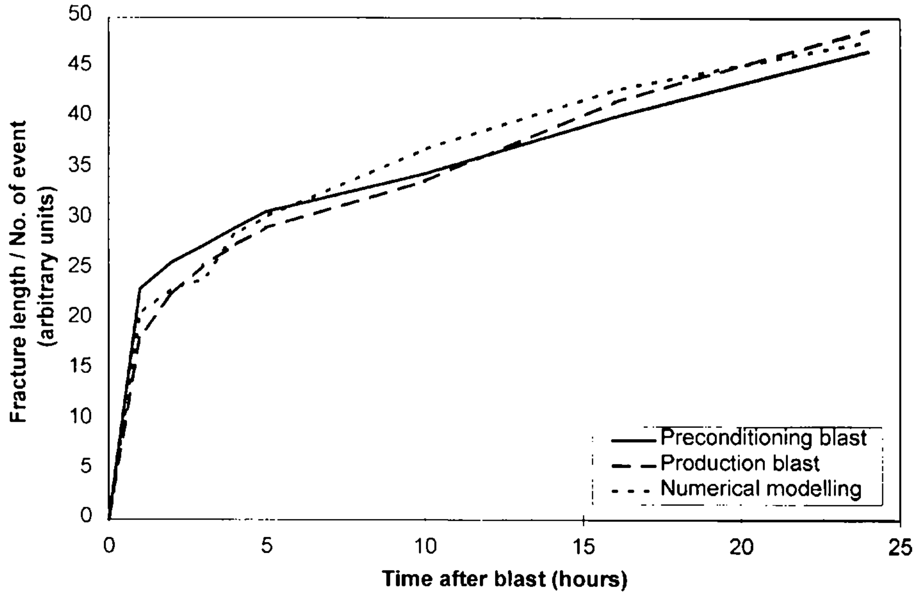


Figure 4-2: Comparison of total fracture length around an advancing stope as derived from a viscoplastic model with actual recorded seismicity subsequent to blasting at the Blyvooruitzicht preconditioning site (after Malan and Spottiswoode, 1997).

As stated above, the process of rock mass deformation near the stope face must be reflected in the rock mass response in the stope itself. Convergence recorded following a blast should reflect the time-dependent effects of the fracture zone. When the discontinuities generated within the model were subjected to a time-dependent decay in the cohesive strength, the convergence resulting from several mining steps approximated the response recorded from within the stope (Figure 4-3). Unfortunately, there is a limited amount of this type of continuous convergence data from the 17-24W stope. Limited use was made of the required instrumentation due to the number of damaged instruments resulting from installations close to the face, which is required to ensure that the data are indicative of the rock mass behaviour at the stope faces and not a response from some more distant event.

The continued convergence recorded some time after the blast (Figure 4-3) could be an indicator of the degree of strain energy accumulation within the rock mass. If this is the case, time-dependent responses could be used to 'predict' anomalous rock mass behaviour, which could be an indication of the necessity to precondition that particular production face.

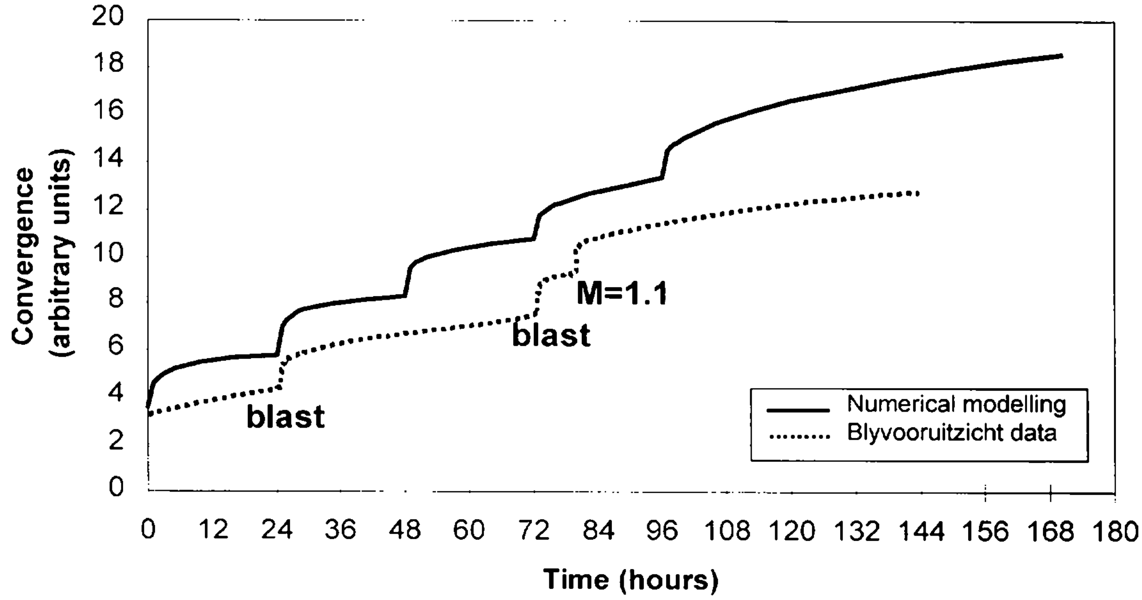


Figure 4-3: In-stope convergence associated with blasting (face advance) as determined by a viscoplastic model compared to that measured at the Blyvooruitzicht preconditioning site.

A relatively large seismic event near the face results in a similar trend in the convergence rate.

The next step in this work would be to investigate the effect of preconditioning on the time-dependent response. Although the seismic database (as well as convergence/ride data) for the BGM 17-24W site is relatively complete, the amount of continuous convergence data is limited and the data recording itself has been unreliable at times. Initial results should, however, form the foundation for further investigations from other sites. It would seem that there is potential for the use of in-stope convergence measurements for cost-effective rock mass monitoring, at sites where the seismic coverage is less adequate.

The usual convergence-ride results (Piper and Gürtunca, 1987) are termed *long period* measurements, as these are obtained by taking daily convergence readings with typically a 24 hour interval between successive data points. The profile 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. The true time-dependent behaviour of the rock can be identified by using convergence instruments (such as clockwork convergence meters) recording in a continuous fashion. Typical continuous convergence results obtained for a VCR panel are illustrated in Figure 4-4.

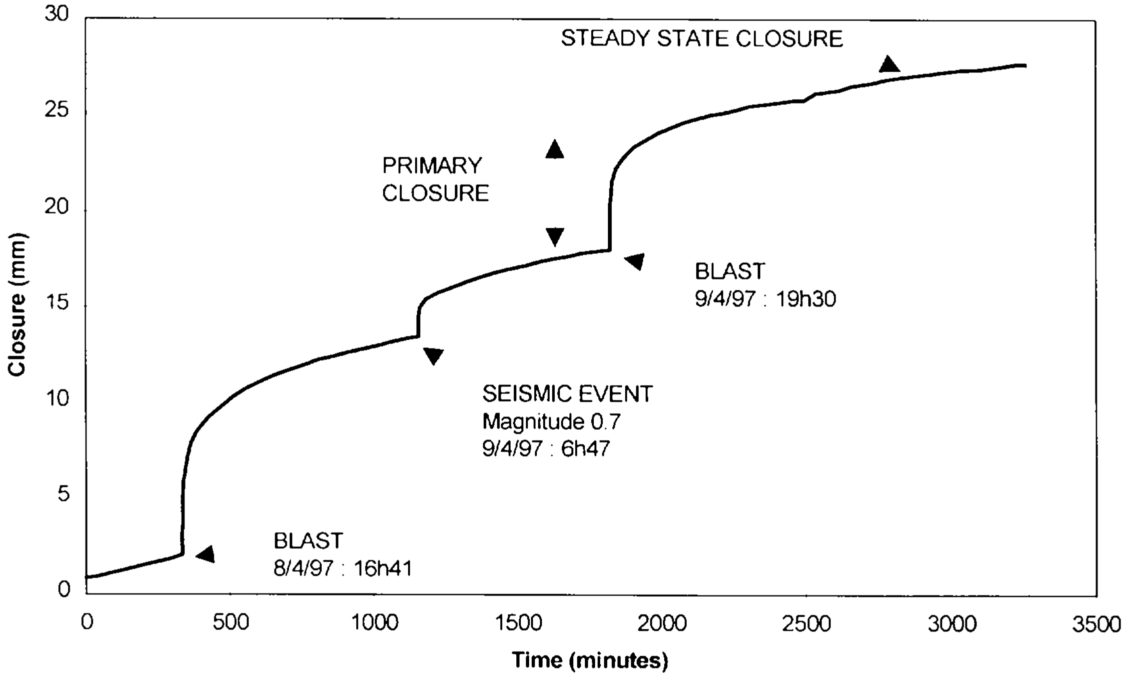


Figure 4-4: Typical time-dependent convergence data measured with an instrument that records in a continuous fashion (after Malan, 1998).

Note that there is a primary convergence phase (including an instantaneous increase) at blasting time, followed by the steady-state convergence phase. This detailed information is lost if only daily measurements are taken. For stopes in the VCR with hard lava in the hangingwall, the instantaneous convergence at blasting is prominent and forms a significant portion of the daily convergence. However, Malan (1998) also found that the instantaneous convergence at blasting time decreases as the distance from the face to the measuring instrument increases. With sufficient distance from the face, it may disappear entirely. The relationship between continuous and daily measurements is illustrated in Figure 4-5. Note that these profiles are not real data, but were generated from an analytical time-dependent convergence solution.

Of importance to preconditioning is that preliminary studies (Malan, 1998) indicated that, for areas prone to face bursting, the instantaneous response close to the face is very large, while the steady-state convergence rate following this is small. In areas where the risk of face bursting is low, it appears that the instantaneous response is small, followed by a high steady-state convergence rate. These measurements could, therefore, be developed into a measure to identify areas where preconditioning should be applied. It should, however, be emphasised again that further work is necessary to prove this hypothesis. Modelling indicated that the instantaneous response is the result of the instantaneous stress redistribution following a mining increment. For stopes with a high stress peak close to the face (considered to be a face bursting hazard), there is a large redistribution of stress after blasting and, therefore, a significant instantaneous convergence response. For stopes where the stress is low in the face area, the instantaneous response is small. High steady-state convergence rates, on the other hand, indicate a greater mobility of the rock mass, which results in the stored strain energy in the face area being dissipated in a non-violent manner.

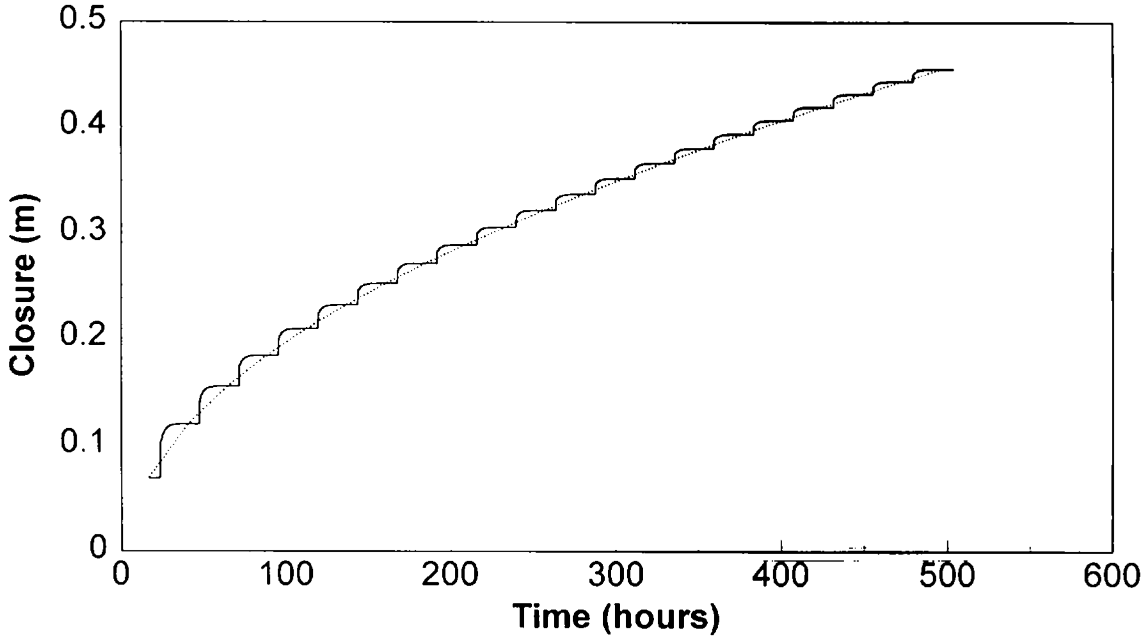


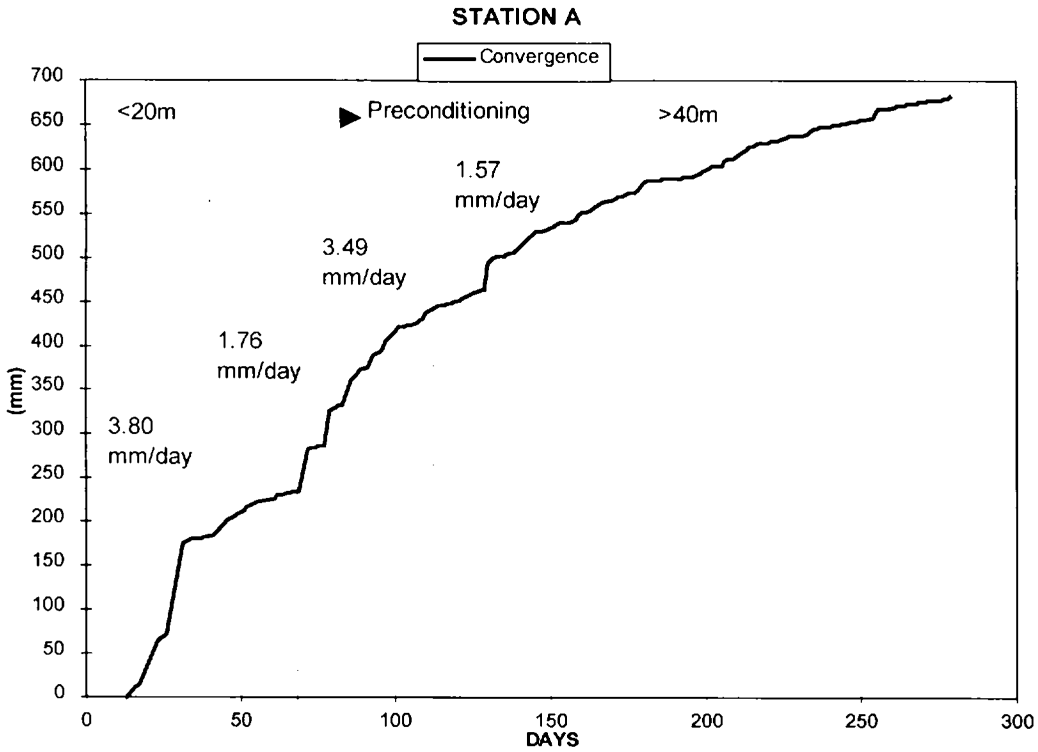
Figure 4-5: Relationship between continuous (solid line) and daily (dotted line) convergence measurements. (after Malan, 1998).

Note that the instantaneous increase at blasting time decreases as the distance to face increases. With sufficient distance to face, the daily convergence measurements can, therefore, be used to deduce information about the true time-dependent convergence behaviour of the stope.

Although no continuous convergence data were collected for the preconditioning panels at WDLS, useful information can still be deduced from the daily convergence data. Examples of such data are shown in Figure 4-6 and Figure 4-7 (the positions of these four convergence-ride stations relative to the preconditioned face are shown in Figure 4-8). Note that Station A was the closest and Station D was the furthest from the face. The graphs were divided into three regions (i.e. <20 m, 20-40 m and >40 m) by vertical dotted lines indicating the distance from each individual station to the face. The solid vertical line in each graph shows the day of initiation of preconditioning, i.e. the initial portions of these convergence profiles illustrate the behaviour when there was no preconditioning in the panel. As soon as preconditioning was initiated, there was an increase in the convergence rate. It is speculated that this increase is due to both an increase in the instantaneous response at blasting time and an increase in the steady-state convergence rate. The instantaneous response is expected to be larger, as a larger stress transfer will take place due to a larger volume of rock ahead of the face being affected by the preconditioning. This, however, needs to be validated with further experiments, such as continuous convergence measurements on a panel before and after the initiation of preconditioning.

The rate of total 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 4-9 shows that the average convergence rate for the preconditioned panels for a distance of less than 40 m is larger than for the panels with no preconditioning (note that the change is more significant within 20 m). Assuming that, after the initiation of preconditioning, variable factors influencing the convergence rate were changed due to the preconditioning and that the 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 rock mass, which helps to dissipate the stored strain energy.

The results of all convergence-ride measurements are given in Appendix 1. The average convergence rate referred to in Figure 4-9 was calculated from those measurements.



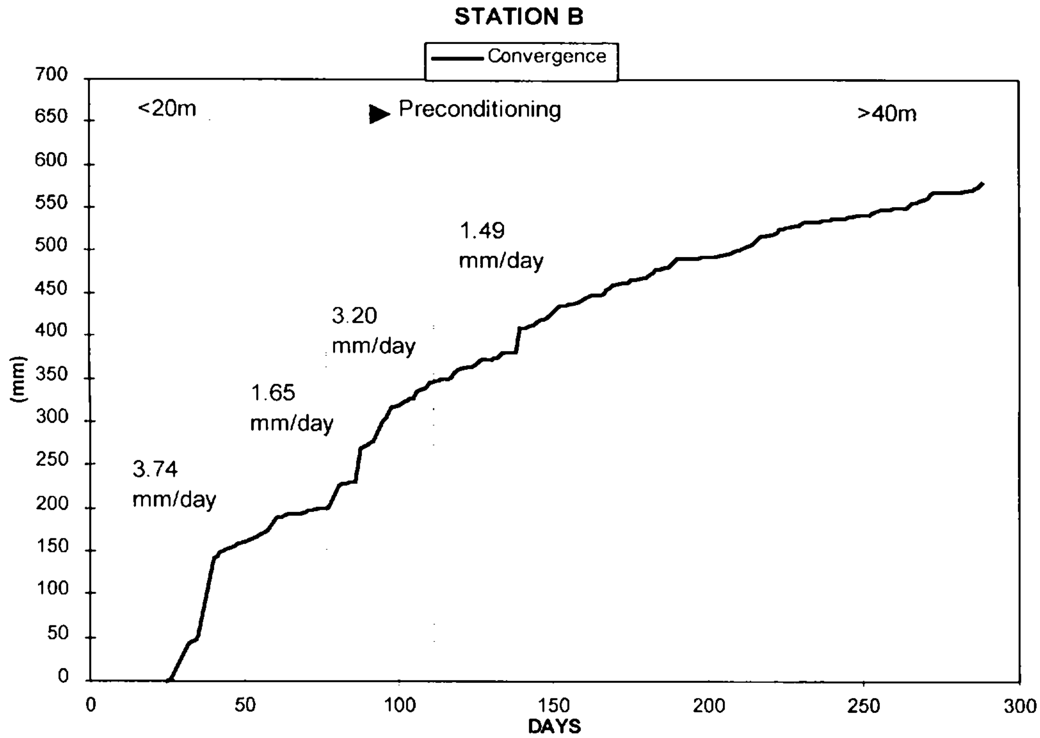


Figure 4-6: Measurements from convergence-ride stations at WDLS 87-49W (Stations A and B).

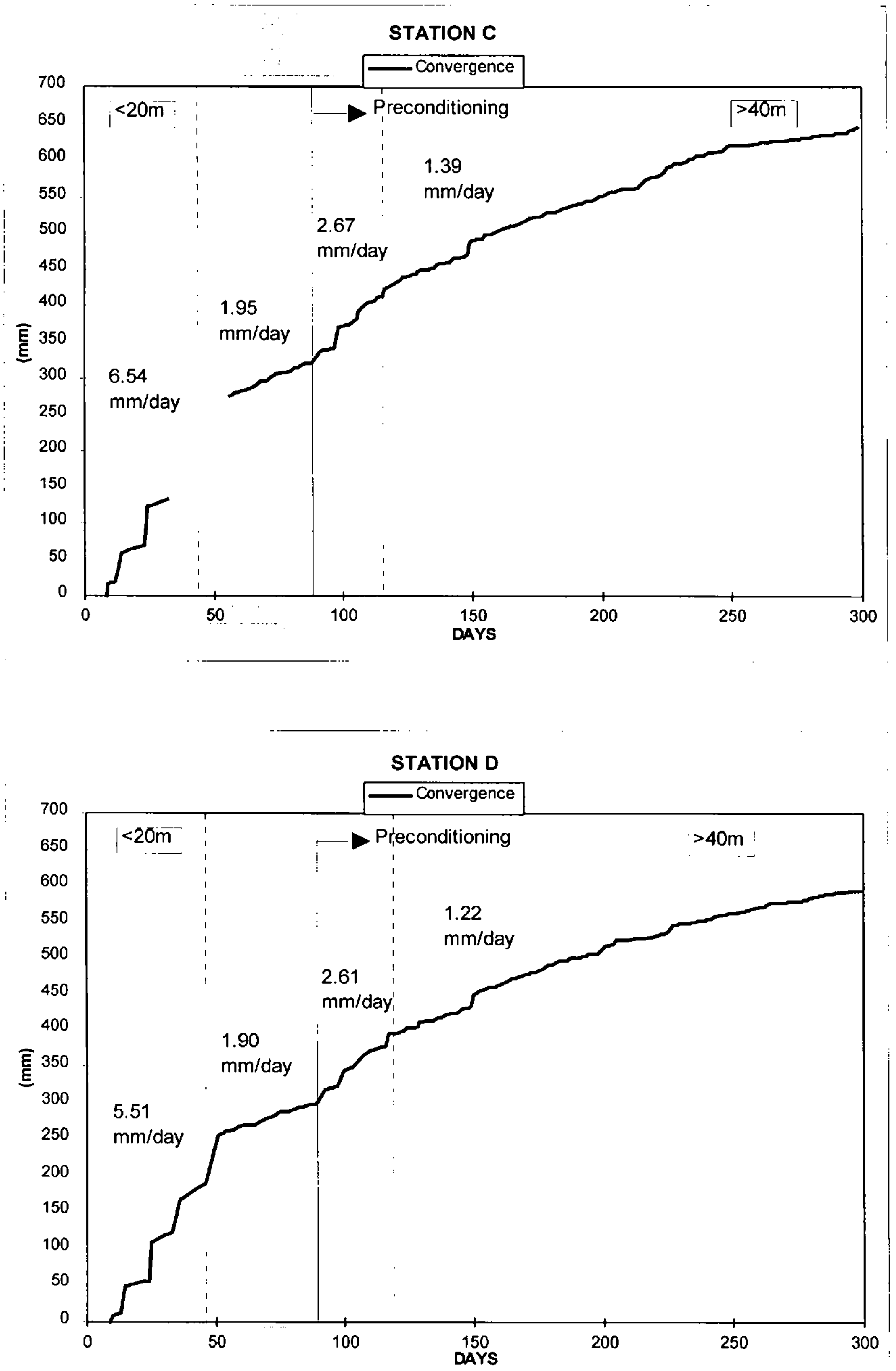


Figure 4-7: Measurements from convergence-ride stations at WDLS 87-49W (Stations C and D).

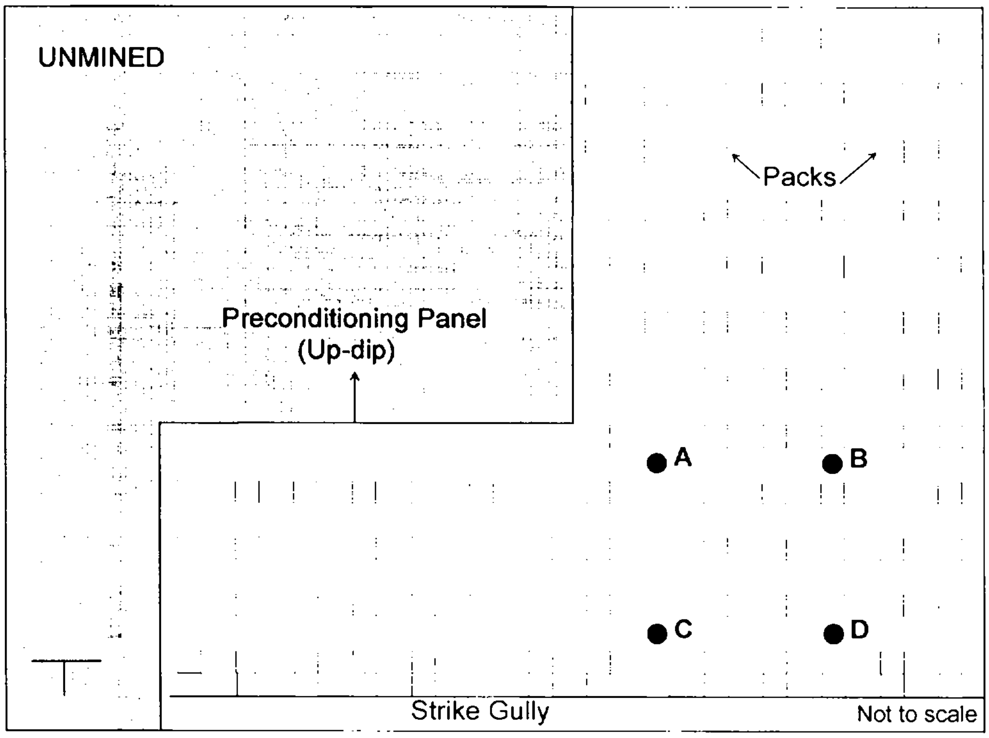


Figure 4-8: Positions of convergence-ride measurement stations (refer to Figure 4-6 and Figure 4-7).

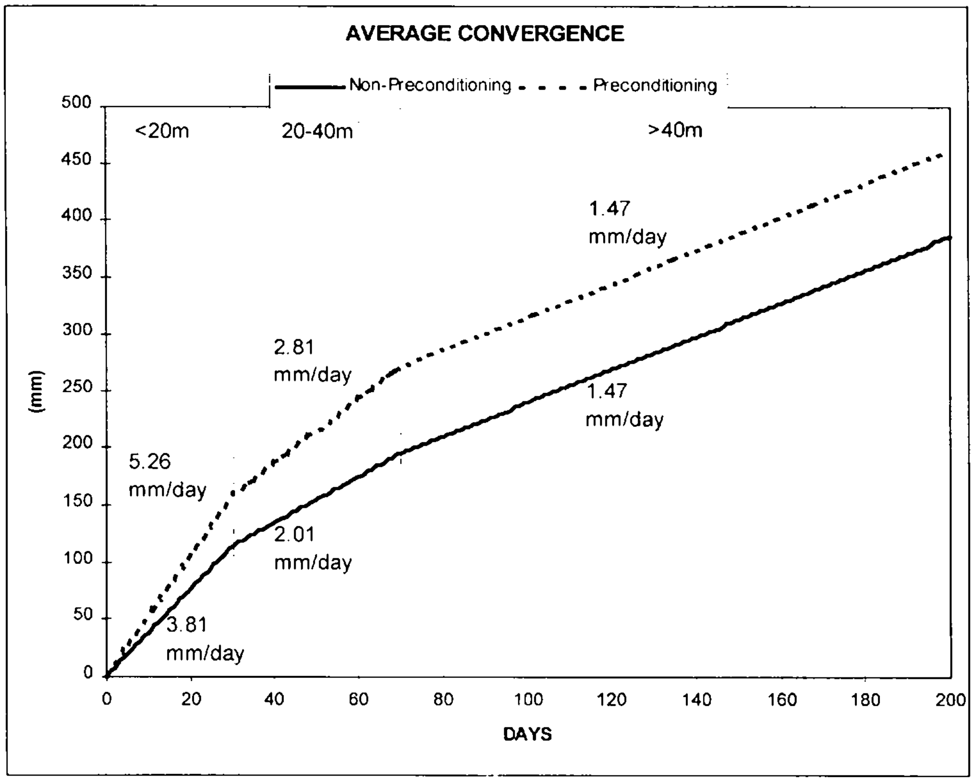


Figure 4-9: Average convergence rates at all (51) stations at WDLS 87-49W for the period from September 94 to March 97.

4.3 Enabling output 1: Face-parallel preconditioning

4.3.1 Blyvooruitzicht Gold Mine

On 30 January 1996, a rockburst from two M>2 seismic events resulted in severe damage to the bottom strike gully (situated in the fracture zone associated with the edge of the pillar). The panel faces themselves remained open, with only scattered falls of ground. It is believed that preconditioning provided considerable benefit with regard to the stability of the hangingwall; this has been seen repeatedly with other events of similar magnitude.

During a meeting with mine management on 13 May 1996, it was decided that the stope would be abandoned and the preconditioning experiment would come to an end, as the amount of new information that could be gained from this site would be minimal and as the project funds would be better utilised in a new project stope. Following that decision, the preconditioning project site at BGM was closed (as of May 1996) and the recovery of equipment was completed shortly thereafter. Data analysis was also completed; a considerable amount of information had been gathered in the previous three and a half years of the preconditioning experiment.

4.3.2 Libanon Gold Mine

The 25-55W pillar was chosen as the project site at which to introduce preconditioning to the mine (Figure 4-10). While the depth of mining is similar to that at the BGM site and the mining situations at the two sites are similar, in that both have to do with the extraction of a strike-oriented stability pillar, there are significant differences between the two sites. The reef types are different, implying different rock mass responses to mining and preconditioning. The presence of other pillars in close proximity to the LGM site is likely to have some influence. The irregular geometry of the LGM pillar is expected to introduce some complications. The BGM pillar site had the advantage of ready access to the top and bottom of the pillar, both by way of hangingwall and footwall drives for the installation of seismic monitoring equipment and in terms of gullies by means of which the pillar itself could be accessed ahead of the mining faces. The LGM pillar is unfortunately deficient in both of these respects.

The Kloof mine-wide seismic system was the nearest system to the pillar, but does not adequately cover this area, since the nearest geophones are situated about 2 000 m away. (This system was not designed to provide coverage for this area.) Large magnitude seismic events have been recorded from the area of 25-55W by the Kloof system, but with inadequate location accuracy. This seismicity coincided with the first blasts in the pillar on an up-dip panel which was being mined to establish the breast mining faces. It appears that an off-shift M=3,3 event resulted in severe damage to the up-dip face in the early stages of mining.

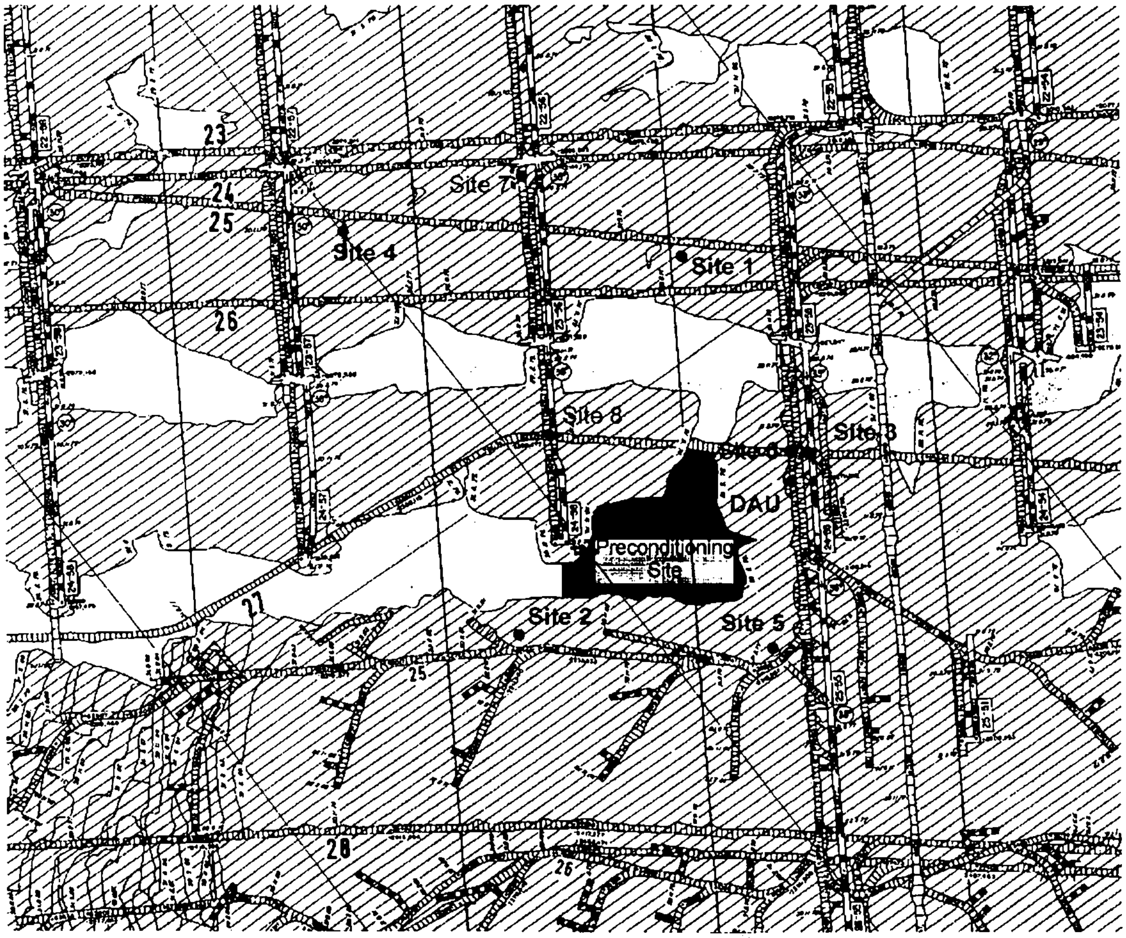


Figure 4-10: Plan of the preconditioning site on Libanon Gold Mine.

The geophone sites (e.g. Site 1) of the microseismic network that is installed at the 25-55W stability pillar are shown, as is the control room (DAU).

A microseismic network (PSS) was designed and commissioned to monitor the seismicity associated with production and preconditioning activity at the pillar. Although it was decided that face-parallel preconditioning activity at the site would not be initiated until adequate access-ways and a suitable face configuration had been established, the seismic monitoring has been continued, in order to compile a seismic database prior to preconditioning.

The planned mining sequence is to establish two breast faces on the south side of the stope and take one preconditioning blast on each face (Figure 4-11). Attention will then be transferred to the north side, which will be mined out via a number of breast faces (these being established through up-dipping, where necessary). Face-parallel preconditioning holes will be drilled from gullies positioned in mined-out ground.

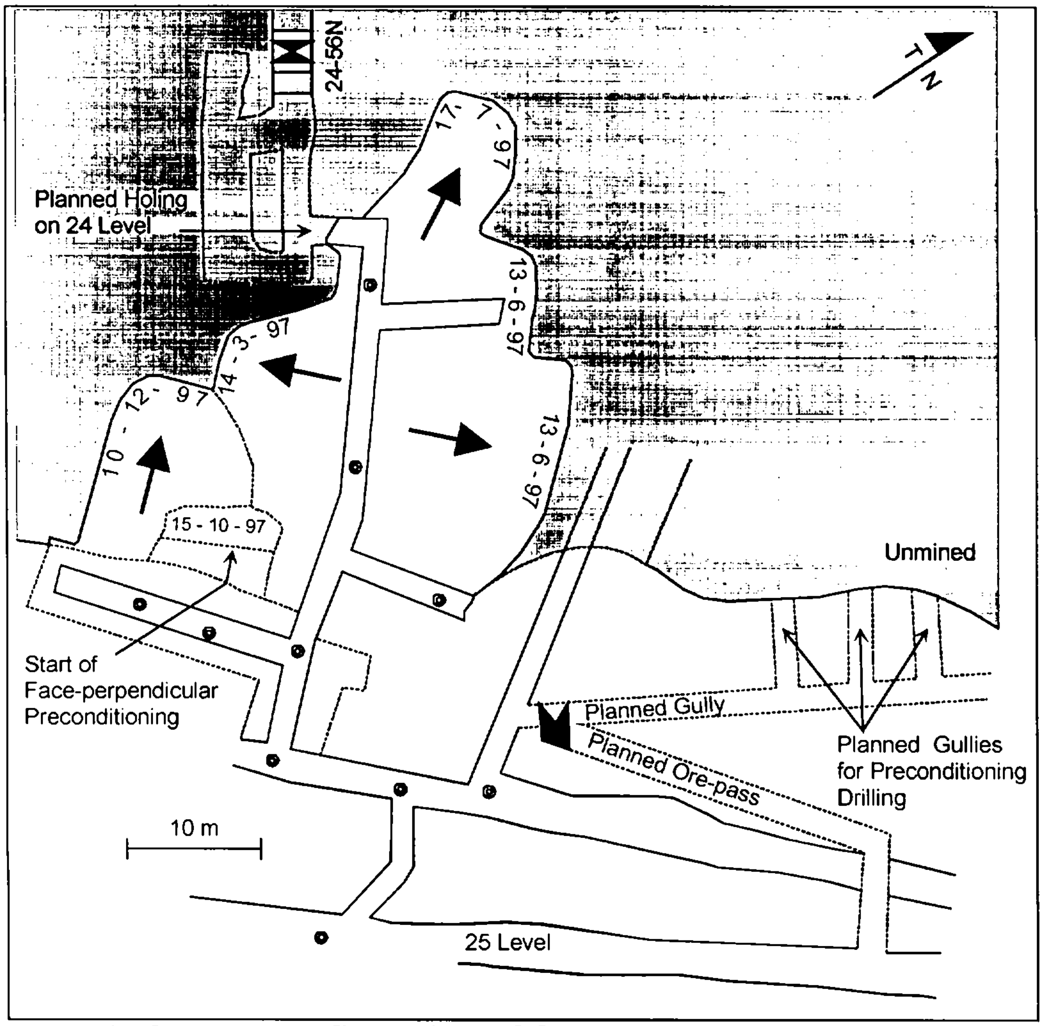


Figure 4-11: Current configuration of faces and gullies in the stope at the LGM 25-55W pillar.

The prominent arrows indicate recent mining directions.

During late 1997, face-perpendicular preconditioning was introduced to the face which was being mined up dip in order to establish the breast faces on the south side of the stope (Figure 4-11). In the space of the more than 5 m of face advance which has taken place since then, improvements in the face advance rate and in the condition of the hangingwall have been reported by production personnel.

It is expected that face-parallel preconditioning will be started on breast mining faces early in 1998. One issue that has arisen concerning the use of face-parallel preconditioning in VCR stopes is that of the effect of 'rolls' in the reef on the positioning of the preconditioning hole. The possibility of damage being done to part of the hangingwall by the blast or of the effectiveness of the preconditioning being reduced by conservative placement of the hole has been recognised and suitable approaches to the problem are being investigated. The use of face-parallel preconditioning on the breast faces might need to be reconsidered, in favour of the use of face-perpendicular preconditioning.

4.3.3 The use of stemming with face-parallel preconditioning

The use of tamping is not an issue when considering the face-perpendicular preconditioning technique. The preconditioning holes are stemmed for 1 m from the collar of the hole, and this part of the rock mass is removed by the accompanying production blast. Undesired stress transfer towards the panel face can thus not result from the preconditioning blast.

The current layout of a face-parallel preconditioning blast is shown in Figure 4-12. The hole is drilled parallel to the face of the panel to be preconditioned, in the fracture zone ahead of the face, and extended beyond the length of the panel. The hole is then filled with explosive and top-primed. The hole is stemmed from the collar for a distance sufficient to contain the explosion within the hole: typically, 5 m of tamping material would be used. The length of stemming required results in the undesired stress transfer discussed by Lightfoot et al (1996).

It was initially thought that the stemmed length could be reduced by grouting a short length of the hole near the collar or using some form of in-hole device (a wooden plug, perhaps, or a packer or wedge), as shown in Figure 4-13. Apart from possible difficulties involved in clearing out such material in the event of a misfire, it became evident from tests conducted at the BGM 17-24W preconditioning site that shortening the stemmed length was not desirable, in any case.

The purpose of the stemming is not only to contain the explosive within the hole, but also to hold all of the fractured rock around the collar of the hole in place. The length of stemming required to achieve this containment is determined by the stress regime and the fractured nature of the rock mass in the vicinity of the collar. Conservatively, the hole should be stemmed from the collar for a distance at least equal to the depth of the zone of fractures oriented perpendicular to the axis of the hole. Clearly, then, some alternative means must be devised to alleviate the stress loading that has been found to occur in the vicinity of the stemmed portion of the hole.

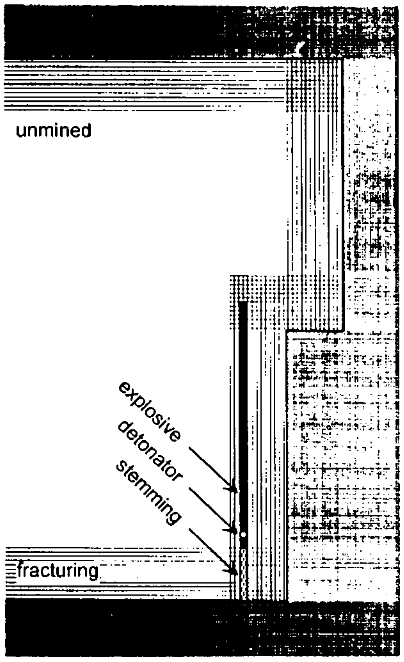


Figure 4-12: Current layout of face-parallel preconditioning holes.

A possible solution to the problem could be to design the preconditioning blast so as to eliminate the need for tamping material, as illustrated in Figure 4-14 (a). If the hole was bottom-primed, the explosive between the collar of the hole and the advancing explosion front would act as stemming for the blast. This arrangement has certain practical disadvantages, however. Inserting the detonator at the end of the hole would be difficult, as would setting it off reliably. In the event of a misfire, clearing out the detonator could present problems, as well.

It is recommended that explosives of minimal impact sensitivity be used for the preconditioning, so that – in the event of a misfire or of a cut-off of the explosive in the hole – production drilling into the hole would not set off the explosive that had not detonated during the preconditioning blast. The presence of a primer at the back of the preconditioning hole would clearly not be desirable under such circumstances; the detonator should, in fact, be placed as close to the collar of the hole as possible, so as to facilitate recovery of the detonator after a misfire. This would also reduce the probability of a cut-off during initiation of the blast.

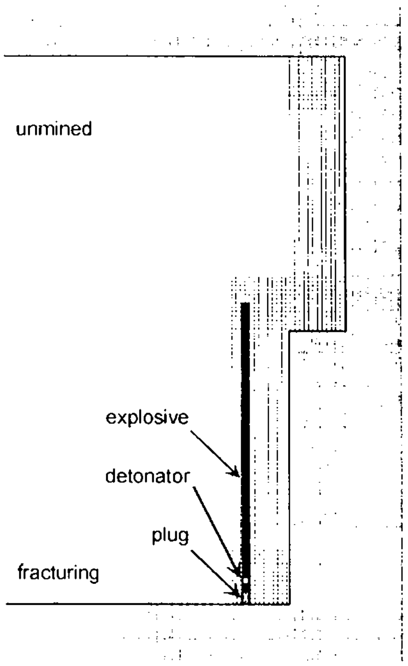


Figure 4-13: Use of in-hole device to shorten stemming length.

A different way to achieve self-stemming of the explosive is shown in Figure 4-14 (b). The basic procedure would be as for Figure 4-12, with the tamping material being replaced by some form of weakened or diluted explosive. This would probably be an explosive of the same type as used in the rest of the hole, but with reduced density (e.g. explosive mixed with some inert substance, such as polystyrene). The explosive between the detonator and the back of the hole would burn as before, while that between the detonator and the collar of the hole would burn with somewhat diminished intensity, providing some preconditioning effect in the previously unaffected part of the rock mass. If the self-stemming effect on its own is not found to be sufficient to prevent blow-out of the explosive from the collar of the hole, some form of removable plug could be inserted at the collar for increased containment.

An alternative to the self-stemming discussed above could be to drill additional shorter holes of smaller diameter between the main hole and the panel face to precondition the area not suitably affected by the main preconditioning blast. Figure 4-15 (a) illustrates this concept for an extra hole drilled parallel to the main hole. Such an arrangement would need to be carefully designed to take into account the influence of each blast on the other hole and to allow for the treatment of possible misfires. The second hole could possibly be timed to detonate just after the main hole, but this could have an adverse effect on the ability to clean the main hole in the event of a misfire of the main preconditioning blast, if the secondary blast does occur.

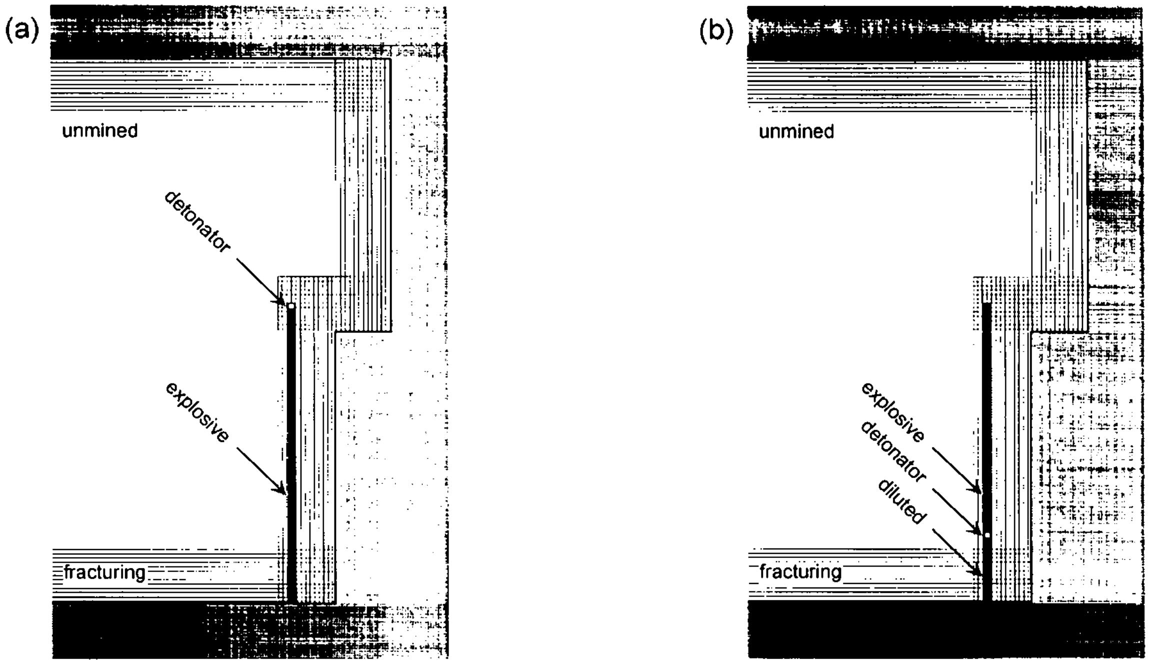


Figure 4-14: (a) Use of bottom priming and self-stemming of explosive. (b) Use of weakened (diluted) explosive as stemming.

A layout which would probably be more amenable to practical application is shown in Figure 4-15 (b). The idea would be to set off the main face-parallel preconditioning blast as usual. Additional face-perpendicular preconditioning blasts could then be set off, with the normal production blast, in the stemmed area, to counter any possible undesirable stress transfer resulting from the main preconditioning blast. In practical terms, this timing of the secondary preconditioning blast would avoid the possible adverse effects of the various preconditioning blasts on the other preconditioning holes. The delay between the primary and secondary preconditioning should not create problems related to undesirable stress transfer, as the build-up of stress in the stemmed area appeared to take place progressively, over several production blasts, at the BGM 17-24W project site.

These possible ways to alleviate the stemming problems were to have been investigated at the BGM preconditioning site, but that project was unfortunately prematurely terminated. The investigation is to be conducted at the LGM 25-55W site, once preconditioning has been initiated there.

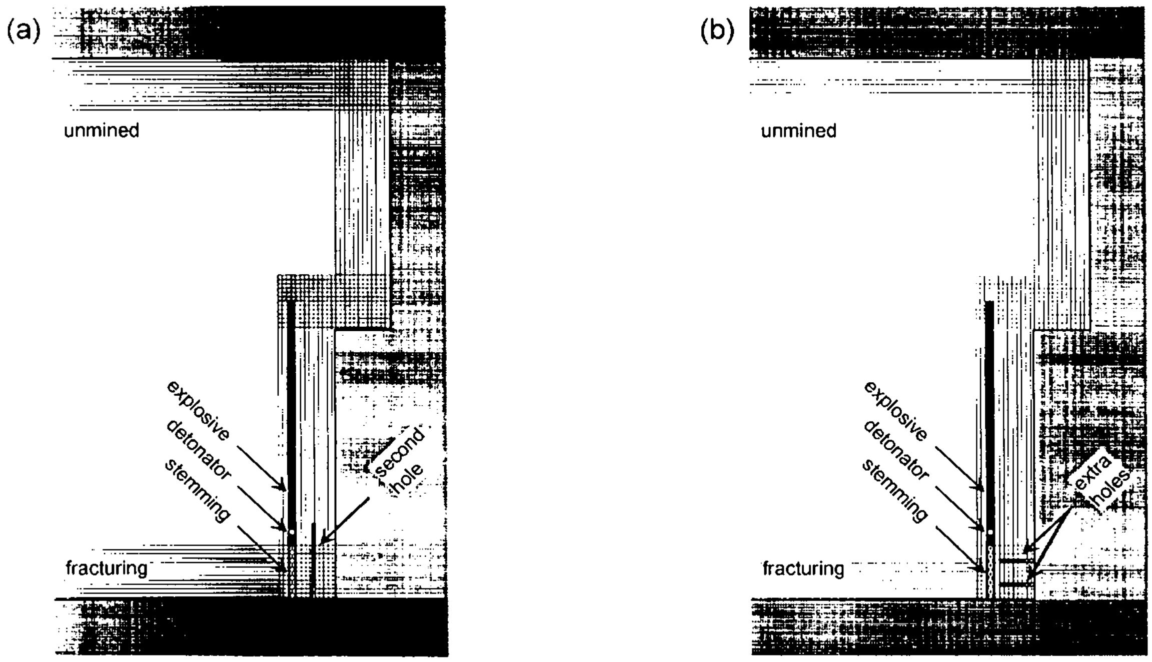


Figure 4-15: (a) Use of second hole, parallel to main hole, to precondition stemmed area. (b) Use of additional holes, perpendicular to panel face, to precondition stemmed area.

4.3.4 Guidelines for face-parallel preconditioning

Guidelines for the use of long, large diameter, face-parallel holes for preconditioning stope faces as a tool for safe mining of remnant pillars at depths of between 1 000 m and 3 000 m have been developed, and are attached to this report as Appendix 2.

4.4 Enabling output 2: Face-perpendicular preconditioning

4.4.1 Western Deep Levels South Mine

The primary objective of preconditioning is to reduce the risk of potential face bursts and minimise the damage caused by any seismic event that occurs in the vicinity of the face. Since the preconditioning experiment was initiated in the West panels of the 87-49 longwall on 25 May 1995, no face burst has been reported from a preconditioned panel. However, some slight injuries were associated with the incorrect or ineffective application of preconditioning, as discussed below.

Case 1: A seismic event (M=2,0) which was located very close to the preconditioning panel (West 4) occurred on 25 July 1995. Although significant damage was observed in West 5 (unpreconditioned) panel, the preconditioned panel showed no damage at the face or in the hangingwall. The event produced falls of ground in the back areas, which resulted in cut-offs and the consequent misfiring of all stope faces which had been prepared for blasting.

Case 2: The first preconditioning panel had been mined for almost two and a half months (23/5/1995 to 13/8/1995). Owing to preconditioning, a high face advance rate was achieved in this panel and it reached the planned position earlier than expected. It thus had to be stopped, to allow two other panels to be mined to the stopping line at the stability pillar. A seismic event (M=1,1), which located relatively far (about 30 m) from the preconditioning panel, occurred on 31 August 1995. This particular event was associated with a face burst, which caused some damage at the loose end of the panel and resulted in a fall of ground in the face area. Since the panel had been abandoned two weeks before the event, there was no risk of injury. This event highlights the transient nature of preconditioning.

Case 3: A rockburst on 15 February 1996 caused some damage to one of the diagonal faces. An event of M=1,8 was located within a few metres of the West 2 diagonal panel, resulting in falls of ground and significant scaling of the face, but no ejection from the face. The preconditioning was not being carried out correctly, with the holes being drilled using only 2,4 m drill-steels, while 1,8 m drill-steels were used for production holes (leaving sockets of 40 cm to 50 cm). The significantly reduced preconditioned zone ahead of the face may account for the large amount of face scaling which resulted from the event. It is likely, however, that preconditioning did provide some benefit in preventing what would otherwise almost certainly have been a face burst.

Case 4: Two seismic events (M>1,0), which were located between the preconditioned panel (West 3) and an unpreconditioned panel (West 1A), occurred within a second of each other on 5 October 1996. Although severe damage (extensive falls of ground) was observed in the unpreconditioned panel, the preconditioned panel showed minimal damage at the face and to the hangingwall. The unpreconditioned panel face was closed for over a week as a result of the damage it sustained. However, production continued in the preconditioned panel on the following working day. No injuries were reported due to this incident.

Table 4-1 shows the centares mined per reportable injury (classified as related to seismicity and falls of ground) in the 87-49 longwall West panels from May 1995 to the end of 1996. A clear improvement can be seen 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.

Table 4-1: Safety record for the WDLS 87-49W longwall after the start of the preconditioning in May 1995.

A significant improvement is noted in the preconditioned panels for this 17 month period.

	Safety Record (centares mined/injury)		
	Up-dip	Diagonal	Combined
Preconditioning	2 553	981	1 430
Non-preconditioning	735	377	562
Combined	937	528	741

Following the suspension of preconditioning at the mine, staff at 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, while the face advance rate decreased measurably. It is related that three sites in the vicinity of and including 87-49W were damaged by large seismic events (magnitudes in the range 1,8 to 3,0) in the space of a single week, with 16 rockburst/face burst injuries resulting.

4.4.1.1 Change in fracturing with preconditioning

Five distinct mining-induced fracture groups were identified at WDLS 87-49W stope based upon their spatial orientation (dip and strike). These groups have been labelled Groups I to V and are summarised in Table 4-2. The fractures mapped at the preconditioning site, after the initiation of preconditioning, populated the same five groups identified in the stope before preconditioning was initiated (Figure 4-16). However, the abundances of the fractures within these groups differed between preconditioned and unpreconditioned (normal) areas.

Table 4-2: Summary of characteristics of major fracture types at WDLS 87-49W.

GROUP	DESCRIPTION
I	Low angle, face-parallel extensional fractures (and occasionally shears)
II	Steeply dipping, face-parallel extensional fractures
III	Steeply dipping, face-perpendicular faults and extensional fractures
IV	Moderately dipping (towards face) extensional fractures lying at an acute angle to the face
V	Moderately dipping (away from face) extensional fractures lying at an acute angle to the face

Following the inception of preconditioning, there was a noticeable change in the appearance of the stope. This resulted from a change in the fracturing of the rock mass around the stope. Despite this change, no new groups of fractures formed. Rather, the relative abundances of the existing groups changed. There was a significant increase (25 per cent) in the number of steeply dipping fractures, whilst shallowly dipping fractures showed a 61 per cent decrease in abundance in preconditioned areas (Figure 4-17 a and b). Fractures with an intermediate dip did not show much variation in abundance between preconditioned and unpreconditioned (normal) areas. In normal areas, fractures with an intermediate dip made up approximately 21 per cent of the total, compared to 27 per cent in preconditioned areas. It can therefore be deduced that, in terms of dip orientation of fractures, preconditioned stopes have steeper dipping fractures when compared with normal stopes.

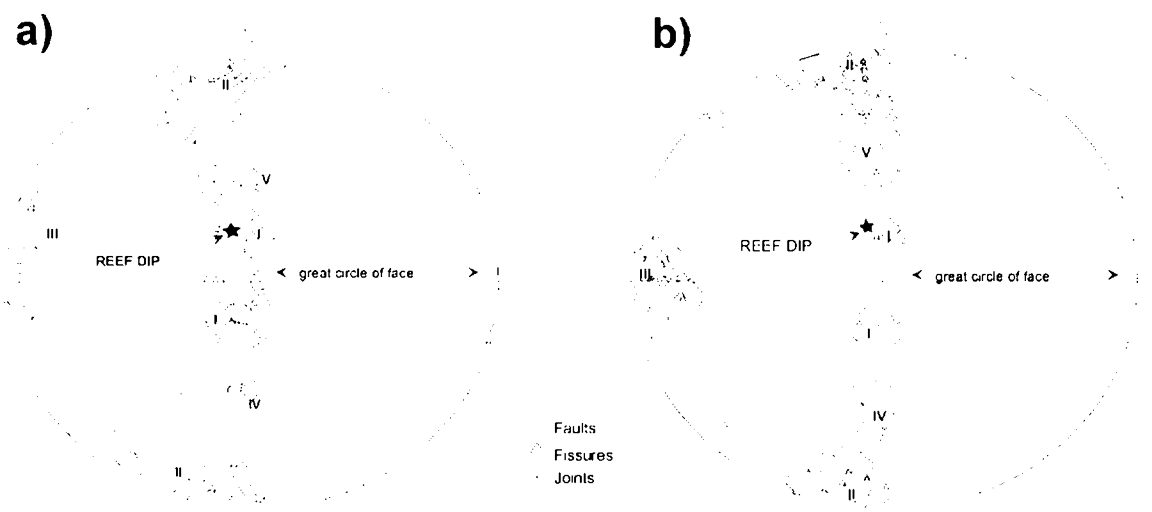


Figure 4-16: Schmidt-net (lower hemisphere projection) of poles to all fractures mapped in the WDLS 87-49W preconditioning site.

a) prior to preconditioning and b) after preconditioning.

The strike orientation of fractures in normal and preconditioned areas also appeared to change (Figure 4-17 c and d). There was a decrease in the number of fractures orientated between 0° to 30° and 150° to 180° (this was a band of more or less face-parallel fracturing). 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 (Figure 4-18). 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 mined up through a zone of fracturing developed parallel to the lag which had formed between adjacent diagonal panels. This led to an increase in the abundance of fractures orientated between 70° and 110°.

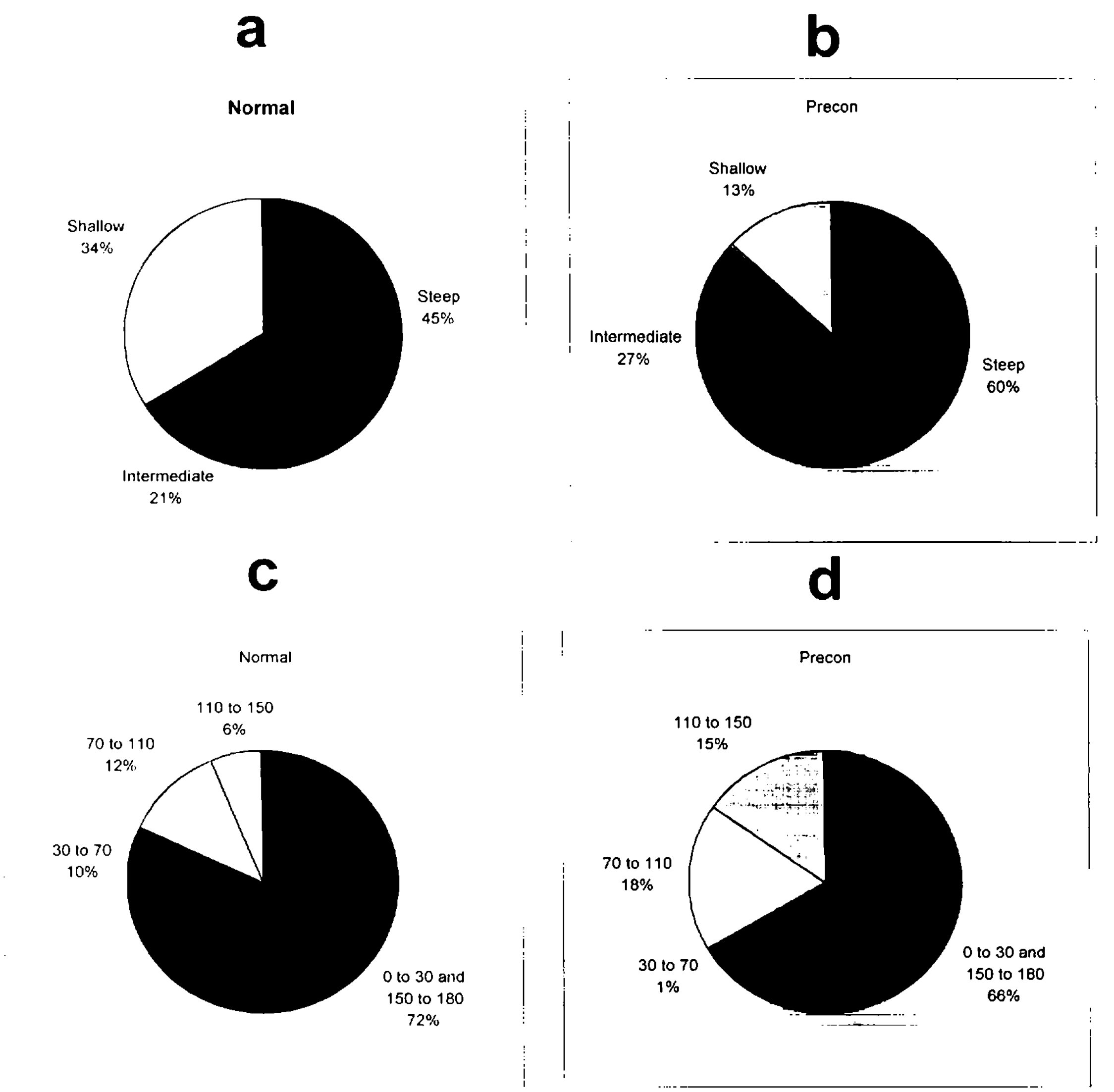


Figure 4-17: Pie charts of orientations of fractures prior to and after preconditioning.

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°.

a) dip orientation prior to preconditioning, b) dip orientation after preconditioning, c) strike orientation (in degrees) prior to preconditioning, d) strike orientation (in degrees) after preconditioning.

As stated previously, the same five fracture groups were identified in both preconditioned and normal areas. The orientation (mean strike and dip vector) of the various groups was very similar for the two areas (Table 4-3). The strike vector azimuth of Groups II, IV and V appears to be very different in preconditioned and normal areas. But the azimuths for the two areas were more or less 180° apart and so, in fact, the fractures in each group were orientated almost parallel to one another. The spherical variance of the different groups was low, especially if compared to the spherical variance obtained if all the fractures were grouped together. (Spherical variance is essentially the total variance of a three-dimensional data set, and describes the extent to which the data differ from a spherical model.) In preconditioned areas, this variance was 47,4, compared with 61,4 in normal areas. Thus, the spherical variance of the groups was two orders of magnitude lower than that of the entire database (Table 4-3). 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 much the same in both mining conditions.

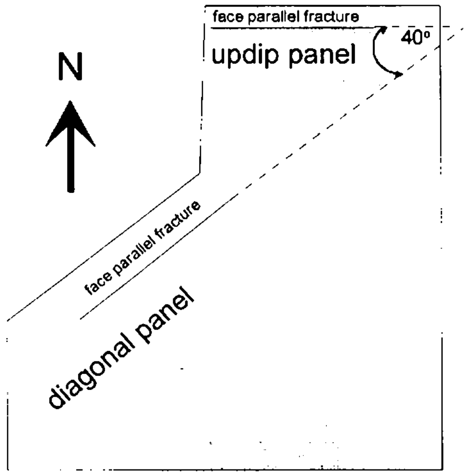


Figure 4-18: Orientation of face-parallel fractures in diagonal and up-dip panels.

Fractures in the diagonal panel are rotated approximately 40° anti-clockwise with respect to those in the up-dip panel. Thus, these fractures appear to occupy the 110° to 150° range (relative to the up-dip face), even though they are actually face parallel.

Preconditioning does not cause the development of new fracture sets. Rather, the relative abundances of pre-existing fracture sets is modified (Figure 4-16 and Figure 4-17). 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.

Group I fractures showed a decrease in occurrence with preconditioning, most likely due to separation on the reef-hangingwall contact induced by the preconditioning blast. In contrast to this, there was a definite increase in abundance of Group II fractures. This increased abundance was not due to the development of new fractures, but rather to the extension of small pre-existing fractures due to preconditioning and later to the production blast. Group IV and V fractures are thought to be formed when blocks created by Group I 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.

Table 4-3: Summary of the characteristics of the various fracture groups.

	Group				
	I	II	III	IV	V
Dip vector plunge (normal)	4,1°	84,8°	75,4°	41,4°	-59,6°
Dip vector plunge (precon.)	7,9°	85,4°	77,5°	47,2°	-48,3°
Strike vector azimuth (normal)	9,9°	1,7°	99,1°	14,6°	17,6°
Strike vector azimuth (precon.)	27,3°	177,6°	85,9°	175,5°	163,7°
Percentage (normal)	26	38	21	7	5
Percentage (precon.)	15	47	24	11	5
Spherical Variance (normal)	0,769	0,550	0,240	0,485	0,242
Spherical variance (precon.)	0,124	0,564	0,162	0,279	0,044

4.4.1.2 Hangingwall profiles

Numerous profiles were measured underground by stretching out a 30 m 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 profile were measured underground. Initially, only the peaks and troughs in the hangingwall along various 10 m profiles were measured. However, it was realised that this irregular data set could not be analysed using more sophisticated methods, such as fractal and spectral analysis. Both these methods require a more periodic data set, and so measurements were taken every 2 cm along a series of 5 m profiles.

Once the data had been collected underground, it was entered in a spreadsheet to facilitate manipulation. Methods such as the cumulative percentage of the size of 'steps' in the profile and the fitting of regression lines to the data proved unsuitable, so other statistical methods had to be employed. It is possible to distinguish between a normal and a preconditioned hangingwall using a spectral method. Figure 4-19 shows the result of performing a Fourier transform on hangingwall profile data and illustrates the variation in profile amplitude with spatial frequency.

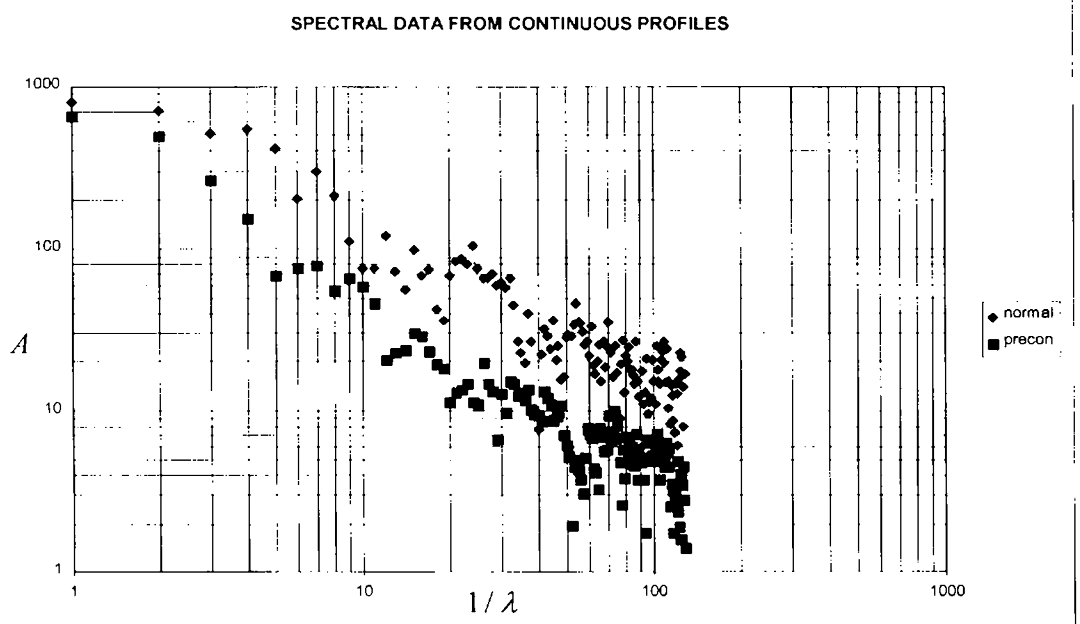


Figure 4-19: Averaged spectral data from all periodic profiles.

Note A is amplitude of spectra and λ is wavelength (from 0,02 m to 5 m).

A variety of statistical methods can also be used to distinguish between a normal and a preconditioned hangingwall. The suitable statistical methods for irregular data include the comparison of profile length, average gradient and average deviation of the data points from the mean. For periodic data, the most viable methods are spectral analysis and a comparison of the moving averages of the profile heights. It was not possible to fit either a self-affine or a self-similar fractal model to the data, because the resulting fractal dimensions were not sensible.

In summary, it is possible to quantify the differences in the condition of preconditioned and unpreconditioned hangingwalls. All of the methods considered show that the hangingwall is less damaged in preconditioned panels, thus reducing the likelihood of fall-out and dilution of the reef. When preconditioning is implemented at other sites, a comparison of hangingwall profiles will be a useful way to quantify the effects.

4.4.1.3 Fragmentation

Each preconditioning blast hole is initiated just prior to neighbouring production blast holes, so that existing fractures are opened up and extended, thus reducing the stress near the face. The production blast should then break the face much more efficiently and a preconditioned panel should show better fragmentation of the material coming off the face than an unpreconditioned one.

Although some sophisticated techniques of image processing of fragmented rock are available, it was 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 stope face prior to cleaning. Ten photographs from each of the two panels were examined and the 10 largest fragments in each photograph measured. The edges of the rock fragments were detected and then traced manually, since the contrast in a pile of broken rock was not sufficient for an automated process. The area of each fragment was calculated using a digital planimeter and the dimensions (i.e. long and short axes) were measured using a ruler.

The averages of calculated areas of the fragments in each photograph are plotted in Figure 4-20, which shows that the fragment area is smaller in preconditioned panels. A reduction of nearly 50 per cent in the average area of fragments and the lengths of the long and short axes (Figure 4-21) was observed in the preconditioned panel. This improved fragmentation from a production blast results in smaller sized particles and a more uniform particle size distribution, thus improving material handling efficiency.

4.4.1.4 Drill hole shape

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

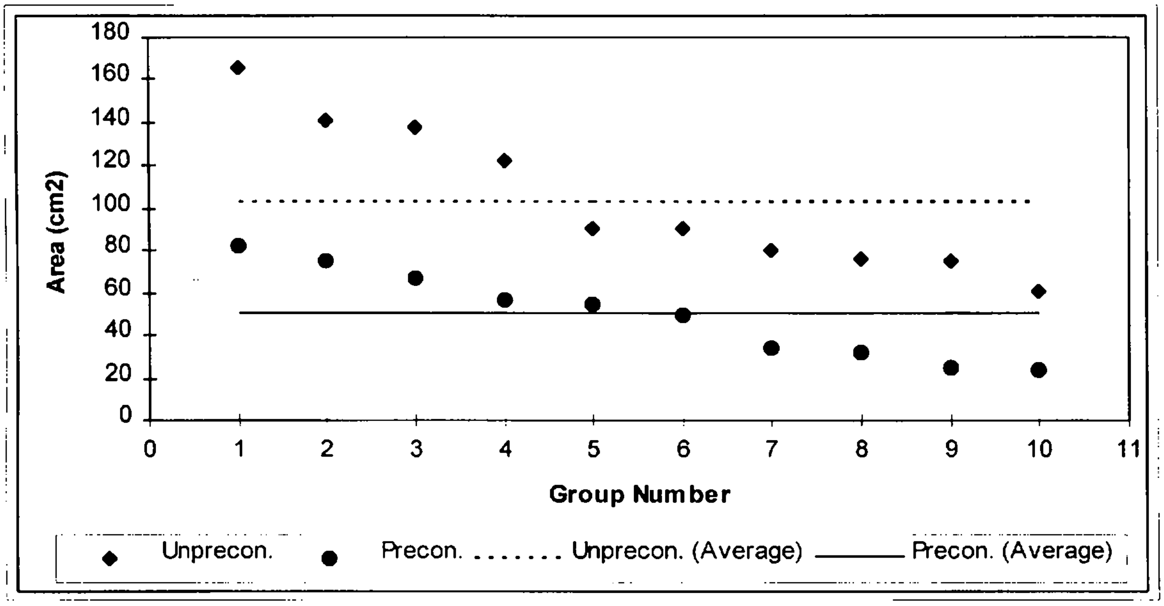


Figure 4-20: The averaged areas of fragments from preconditioned and unpreconditioned panels.

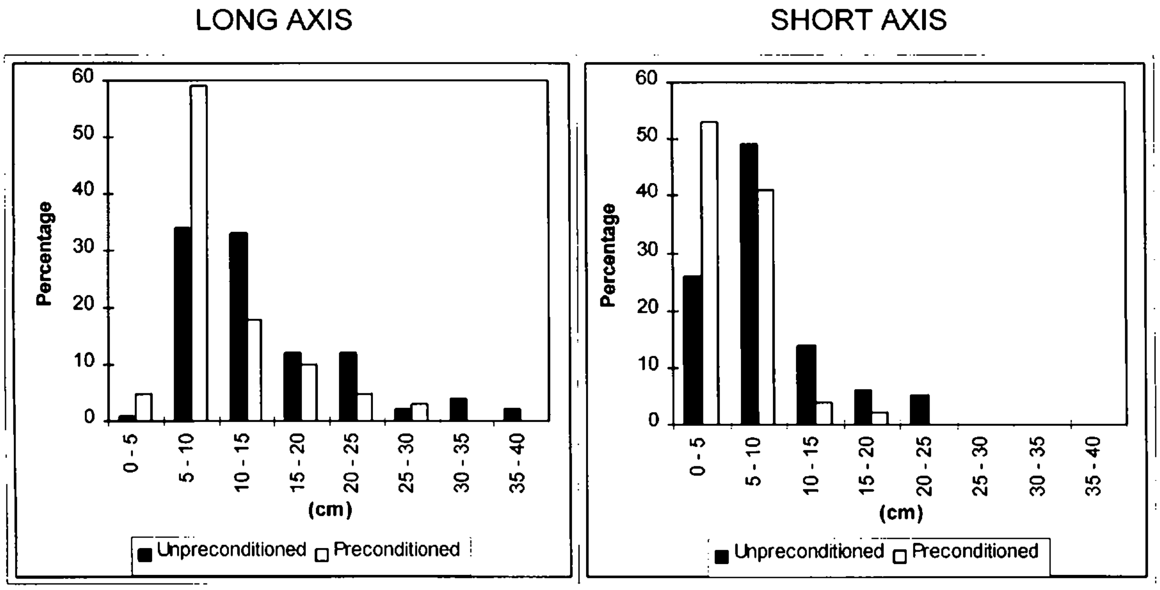


Figure 4-21: The fragment size distribution in preconditioned and unpreconditioned panels.

The shapes of a number of holes in both preconditioned and unpreconditioned panels were determined (Table 4-4). Rigging holes drilled at the top of the face extend beyond production holes and were measured after the blast. Production sockets, although less reliable due to direct blast damage, were used in the same way. The ratio of horizontal to vertical measurements was used to determine the amount of deformation. A ratio of 1 indicates a circular (undeformed) hole; the greater the ratio, the greater the degree of deformation and, thus, the higher the 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.

Table 4-4: Hole shapes in preconditioned and unpreconditioned panels.

	No. of holes	Average (Horizontal)	Average (Vertical)	Average Ratio (H/V)
Unpreconditioned				
Rig Holes	12	43,5 mm	35,4 mm	1,24
Prod. Holes	11	46,4 mm	33,7 mm	1,39
All	23	44,9 mm	34,6 mm	1,31
Preconditioned				
Rig Holes	14	42,5 mm	38,4 mm	1,11
Prod. Holes	25	48,5 mm	45,3 mm	1,07
All	39	46,3 mm	42,8 mm	1,08

4.4.1.5 Stress determination

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 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 rock mass, the suitability of various strain measuring instruments was investigated. Since no existing instruments could be used reliably in a highly stressed and fractured rock mass, there was a need for a specially designed instrument.

A preliminary design of a solid inclusion cell was made in late 1995 and four cells were manufactured early in 1996. Two of these untested instruments were installed at 28 m and 15 m ahead of an advancing preconditioned panel, West 2 at 84-49 longwall. These instruments were installed just above the reef plane, in the lava hangingwall, and were then undermined and retrieved.

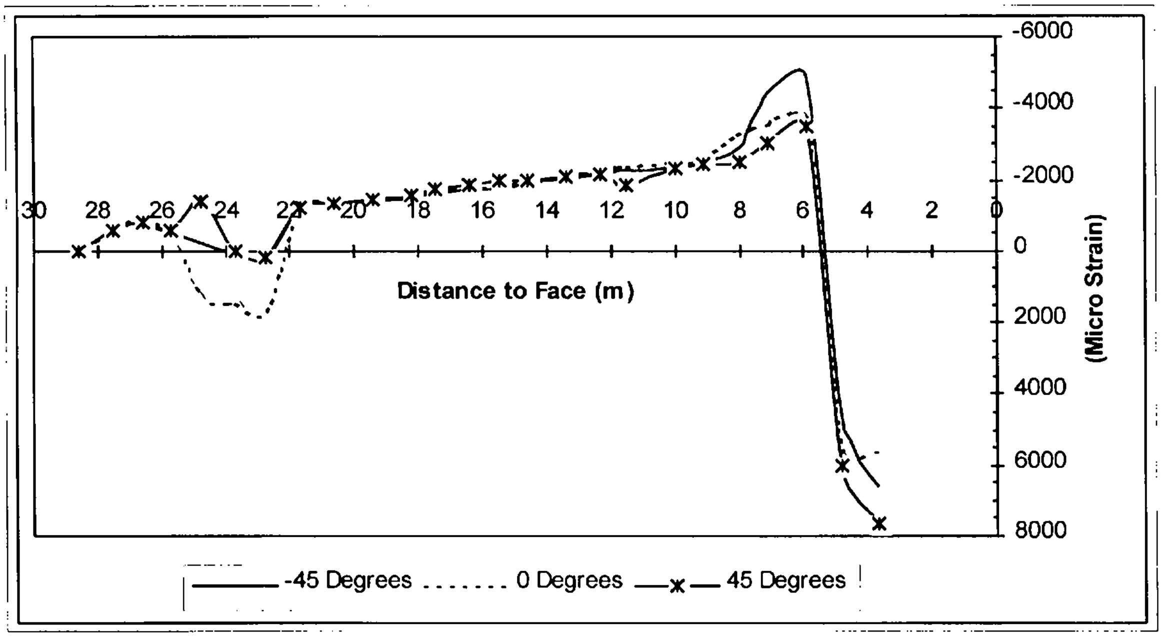


Figure 4-22: The measured strains of the three strain gauges in the B90 Rosette (one of a total of eight Rosettes in the instrument).

This Rosette was oriented in a plane parallel to the face, where the hole was drilled also parallel to the face. The 0° gauge was oriented in the direction of the hole.

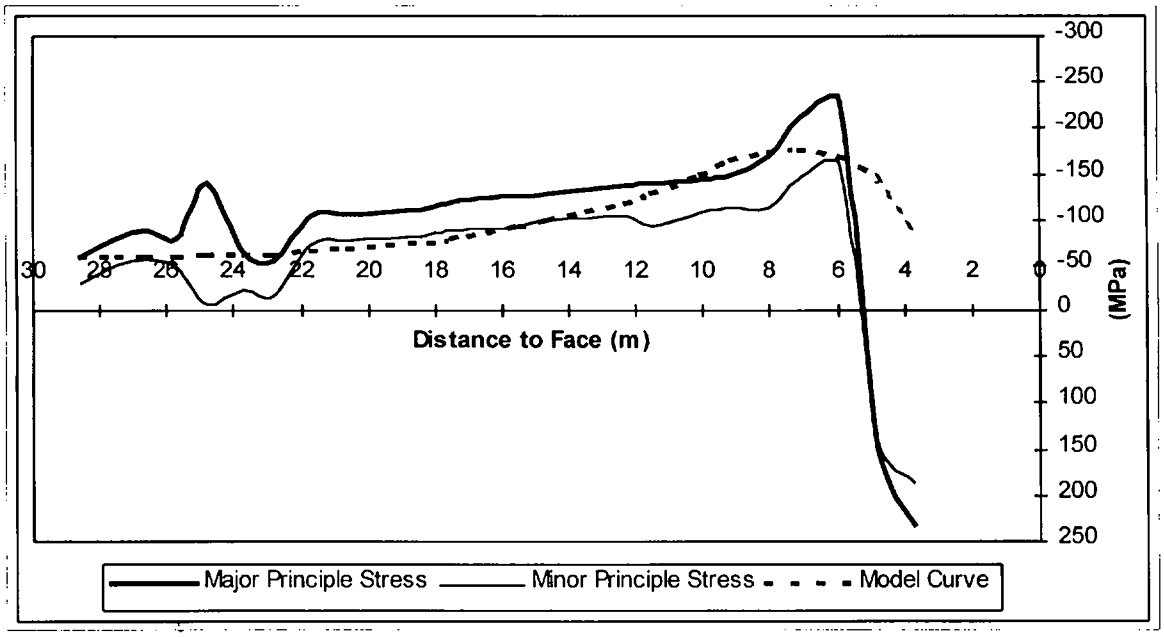


Figure 4-23: Stress profile ahead of an advancing face as obtained from strain measurements taken underground.

An elastic modulus of 28,5 MPa was estimated for the instrument from preliminary laboratory tests and was used to produce these profiles. UDEC modelling results (Lightfoot et al, 1994) were scaled for comparison.

Strain measurements were taken daily as the face advanced towards the instruments (Figure 4-22). 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. Preliminary calibration studies in the laboratory have been undertaken to obtain stress/strain characteristics, which were used to produce the stress profiles illustrated in Figure 4-23.

4.4.2 Optimisation work

In order to optimise the face-perpendicular preconditioning technique with respect to blast parameters (e.g. hole length, hole diameter, hole spacing, explosive amount, etc.), an optimisation experiment was initiated at the end of August 1996 at WDLS. 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-steel lengths was used for a minimum of two weeks for the drilling of 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 various preconditioning scenarios included:

- Seismic Activity
- Rock Mass Fracturing
- Hangingwall Profiles
- Ground Penetrating Radar
- Stope Convergence
- Face Advances
- Drilling Times

A detailed report of the results obtained from each of these measurements is given below.

4.4.2.1 Seismic activity

During 1996, several improvements were made to the PSS network being used to monitor the seismicity from the area around the WDLS 87-49W stope for the preconditioning project. These included the replacement of substantial lengths of underground cabling between the Data Acquisition Unit (DAU) and the geophone outstations near the recording sites. This cabling had been repeatedly vandalised or damaged by mining machinery, so that the maintenance work required to keep the system operational had become prohibitively time- and resource-consuming. The reliability of the system improved considerably following the cable replacement.

The excavation of the 87-49W longwall resulted in the progressive displacement of the area of active mining away from the focus of the seismic network. In an effort to counteract this, two of the recording sites were relocated ('OS2' and 'OS5' in Figure 4-24). A third site ('OS3' in Figure 4-24) was also relocated, partly to improve its position, but also to improve the signal quality at the site (the ground around the previous geophone installation was intensely fractured). The location accuracy for the seismicity from the panels of interest was adequate with the new configuration. Unfortunately, the increased extent of the mined-out ground between the areas of active mining and four of the five recording sites (those other than 'OS2' in Figure 4-24) resulted in an unavoidable loss of sensitivity of the network (with the signals from smaller seismic events being significantly reduced by their passage through the intervening fractured rock mass).

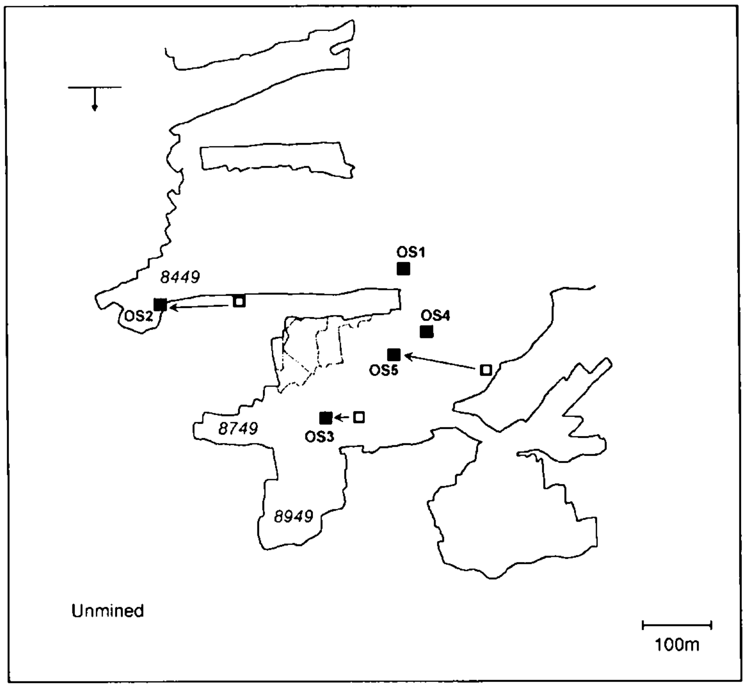


Figure 4-24: Plan of a portion of Western Deep Levels South Mine, showing the configuration of the preconditioning site seismic network.

The earlier positions of three geophone sites are indicated by hollow squares and later positions are indicated by solid squares labelled e.g. 'OS1'. The mining faces are shown as at October 1996. Three stopes are labelled, e.g. '87-49'. Areas mined at various stages under preconditioning are indicated by dashed lines.

During most of 1996, the seismic expression of the effect of preconditioning was masked by the effects of the poor mining configuration, described elsewhere in this report. The discussion of the analysis and interpretation of the recorded seismicity will thus be concentrated 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 87-49W longwall between 26 August and 20 October are shown in Figure 4-25. The seismicity was clearly clustered into distinct spatial groupings associated with the areas of active mining (84-49W stope, 87-49W stope, 89-49 stope and stopes to the east). The mining of 87-49W stope occurred in three panels, labelled 'W1', 'W1a' and 'W3' in Figure 4-26. The W3 panel was the site of the optimisation experiment, while W1 and W1a panels were mined without preconditioning during that 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.

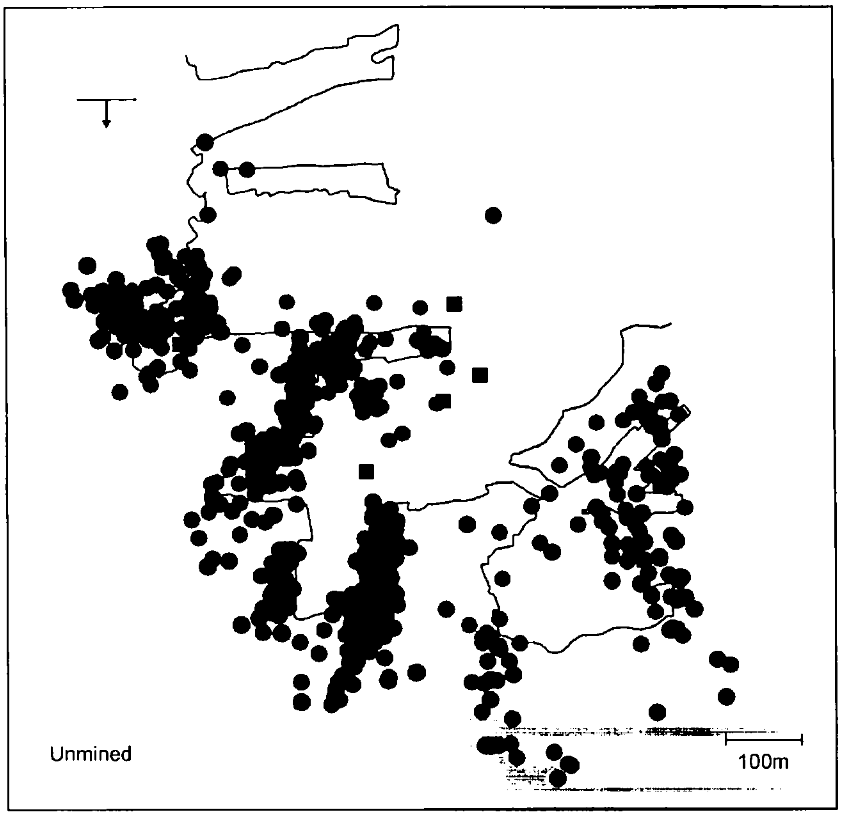


Figure 4-25: Seismic data recorded from 26/08/96 to 20/10/96 by WDLS Preconditioning PSS.

Note clustering in vicinity of actively mined stopes. (927 events shown; –1,54<M<2,86)

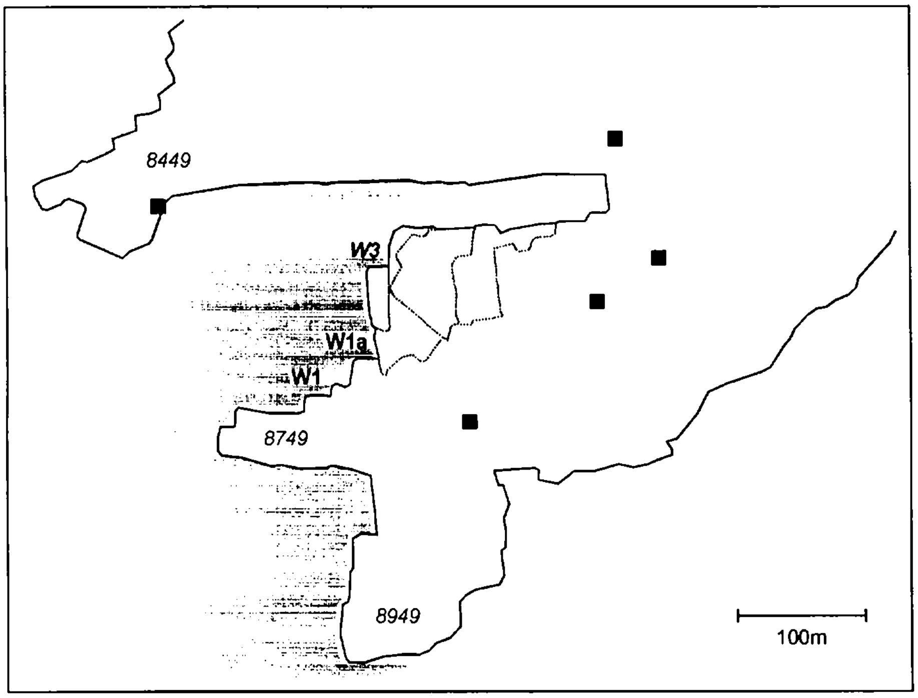


Figure 4-26: Plan of WDLS 87-49W stope.

Three actively mined up-dip panels are labelled e.g. 'W1'. The W3 panel was the site of the preconditioning optimisation study.

The seismic data recorded from the 87-49W stope between 26 August and 20 October are shown in plan in Figure 4-27. The seismicity clustered into areas of mining activity. The clusters associated with the blasting of the footwall development and of a new travelling way into the stope are clearly evident in Figure 4-27, 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 4-27.

The proportions of recorded seismic events of various magnitudes are shown in Figure 4-28, 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 (e.g. 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 4-28 also provides useful information in terms of the recording system. The minimum magnitude (M_{min}) of -0,79 indicates that seismic events of 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.

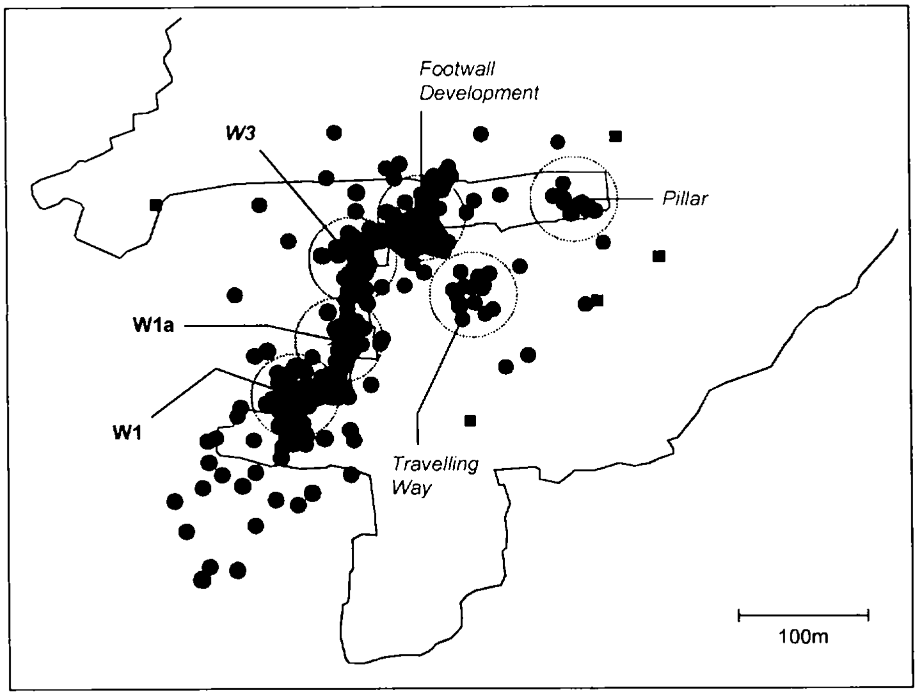


Figure 4-27: Seismic data recorded between 26/08/96 and 20/10/96 from WDLS 87-49W stope by Preconditioning PSS.

Note clustering in vicinity of mining activity. (380 events shown; M>-1,5)

A graph of the cumulative seismicity recorded from the 87-49W stope is shown in Figure 4-29. The seismicity rate was fairly uniform during this period. The plot in Figure 4-29 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 4-29 is confirmed in Figure 4-30, 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 per cent of the seismic events were recorded between 12:00 and 20:00. The peak for development blasting is higher than that for production blasting in Figure 4-30, 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).

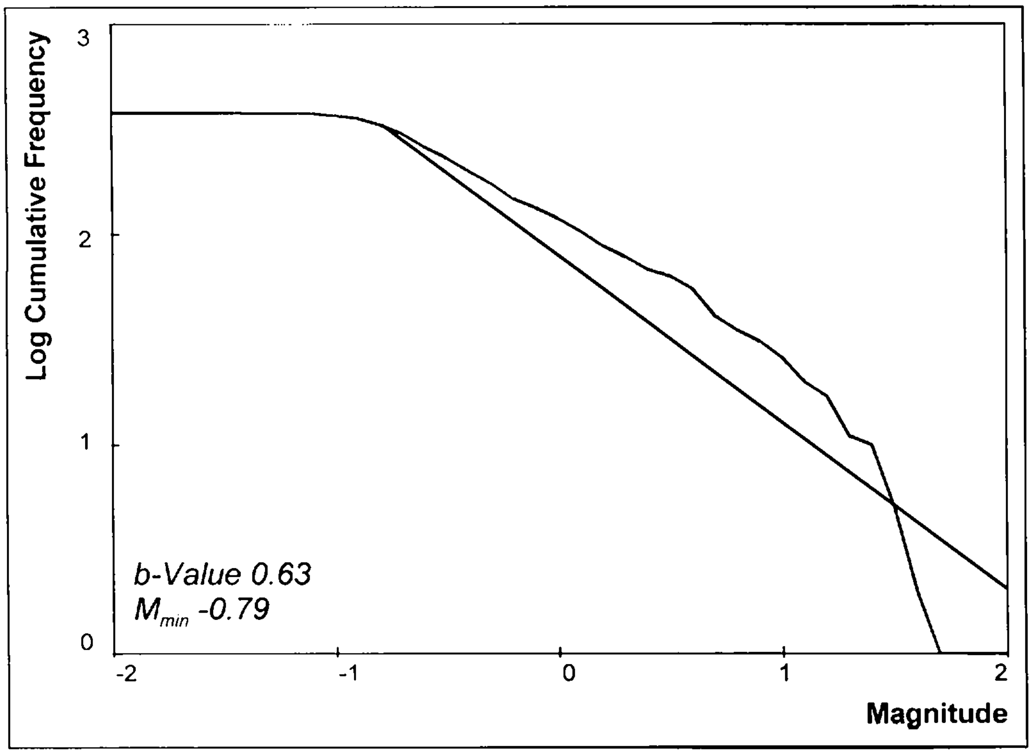


Figure 4-28: Frequency-magnitude distribution of seismic data recorded from WDLS 87-49W stope between 26/08/96 and 20/10/96 by Preconditioning PSS.

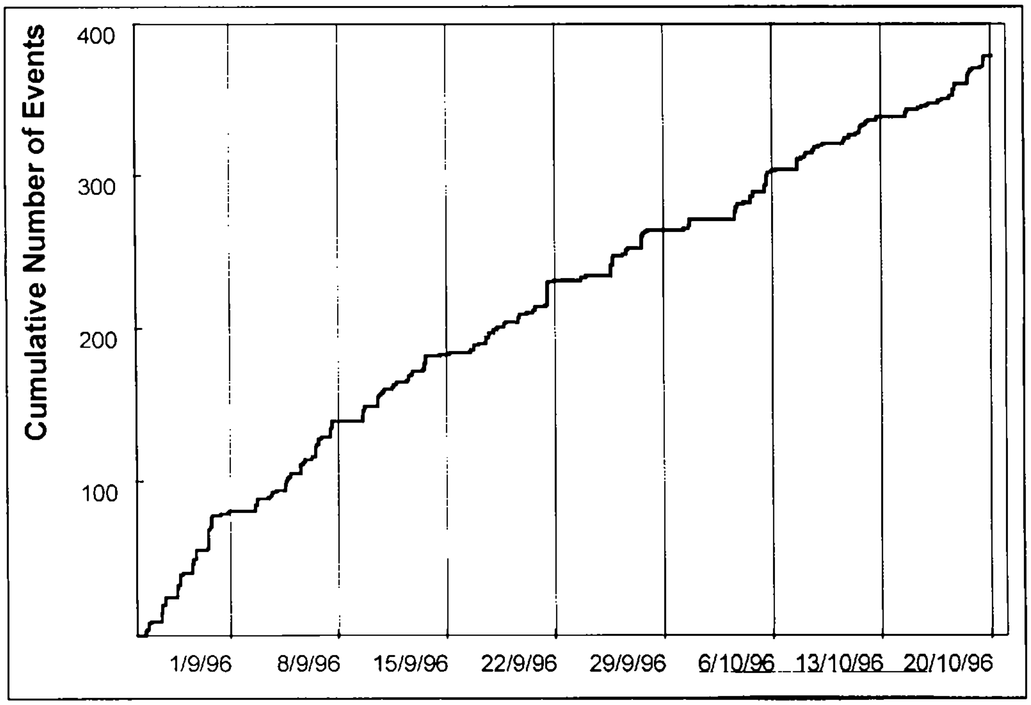


Figure 4-29: Cumulative number of seismic events recorded from WDLS 87-49W stope by Preconditioning PSS.

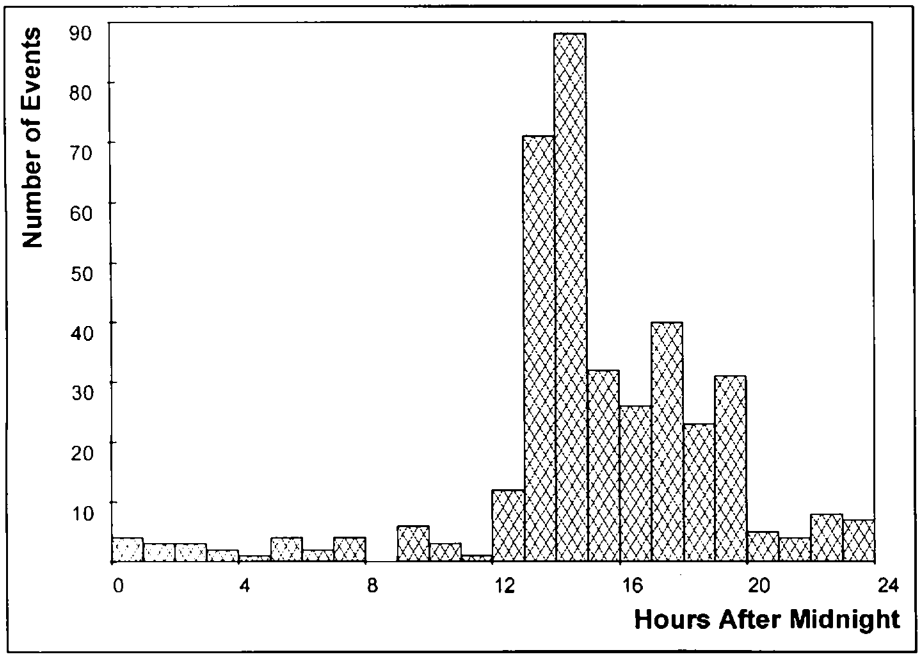


Figure 4-30: Diurnal distribution of seismic data recorded from WDLS 87-49W stope between 26/08/96 and 20/10/96 by Preconditioning PSS.

Note peaks in seismic activity at blasting times (after 13:00 and after 17:00).

Three 'seismogenic regions' were defined from the seismicity associated with the mining of the three panels in the 87-49W stope during the period of the optimisation study, as shown in Figure 4-31. 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 rock mass.

As described elsewhere in the report, 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 are shown in plan in Figure 4-32. 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 4-32 d).

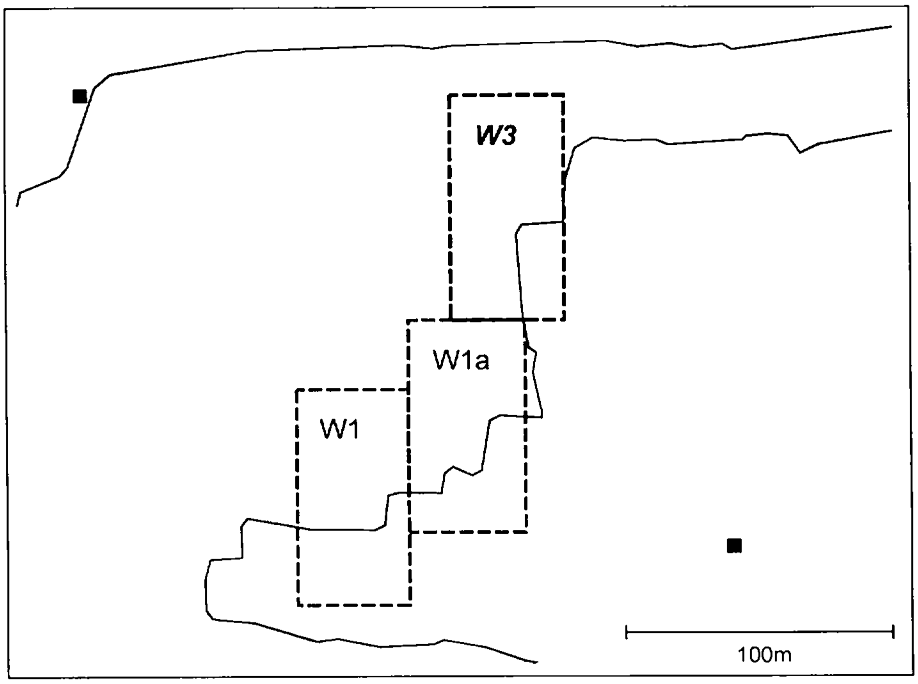


Figure 4-31: Plan of WDLS 87-49W stope.

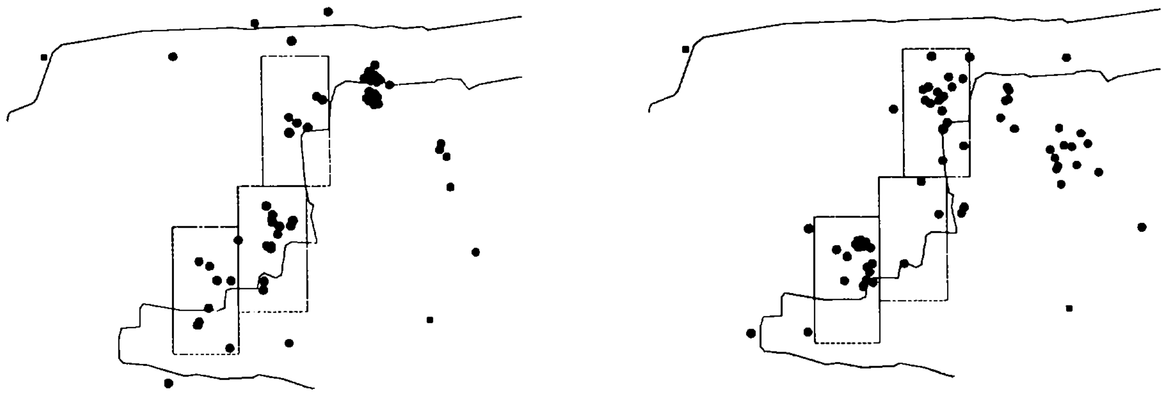
Three 'seismogenic regions', defined from seismic activity associated with mining of three up-dip panels during period of preconditioning optimisation study, are indicated by dashed rectangles.

Some 21 large (M>1) seismic events were recorded from 87-49W stope during the period (see Figure 4-33). Two of these events occurred virtually simultaneously on 5 October 1996. Their locations are indicated by the white stars in Figure 4-33. One of the events occurred ahead of the face of W1a panel and resulted in extensive damage to the panel (the panel having to be stopped for over a week for rehabilitation), while the other occurred close to W3 panel and resulted in very minor damage (associated with shake-out 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 causing noticeable damage to the panel.

The seismic data recorded from 87-49W stope during the period are summarised in Table 4-5. The percentages of larger seismic events recorded from the three panels are higher than that from the stope as a whole, as the stope seismicity included large numbers of development blasts (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, are 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 rock mass.

a) Seismic data recorded from 26/08/96 to 09/09/96 (132 events shown).

b) Seismic data recorded from 10/09/96 to 22/09/96 (90 events shown).



c) Seismic data recorded from 23/09/96 to 06/10/96 (65 events shown).

d) Seismic data recorded from 07/10/96 to 20/10/96 (64 events shown).

Figure 4-32: Plan of WDLS 87-49W stope showing seismic activity recorded during four phases of the preconditioning optimisation study by the Preconditioning PSS.

Dashed rectangles correspond to seismogenic regions defined in Figure 4-31.

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 (see Figure 4-34). This suggests that the preconditioning blasting was effectively destressing the rock mass ahead of the panel face, and that this destressing was remaining in effect for some time following the production blast (i.e. that the panel was made safer, at least for the period during which the night shift was present in the stope).

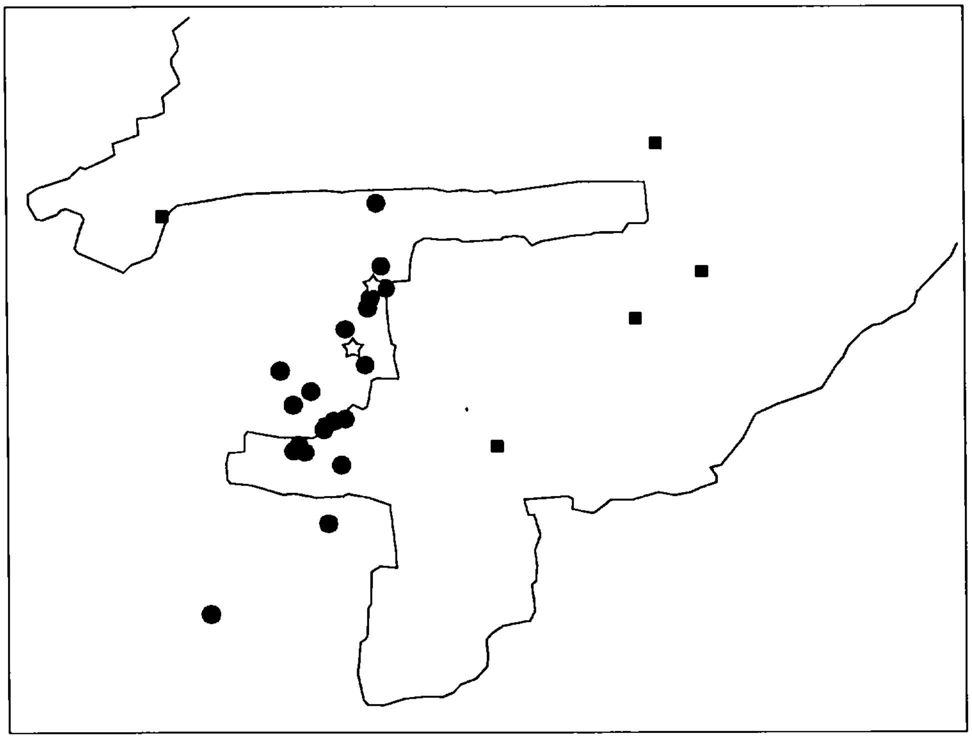


Figure 4-33: Seismic events of M>1 recorded from WDLS 87-49W stope between 26/08/96 and 20/10/96 by the Preconditioning PSS.

The two stars indicate the event doublet discussed in the text. (21 events shown)

Table 4-5: Summary of Seismic Data Recorded During WDLS Preconditioning Optimisation Study*.

				% During Blasting Time**		
	Number	M>0	M>1	Number	M>0	M>1
87-49W	380	103 (27%)	20 (5%)	86	83	80
W3	**52**	**25 (48%)**	**5 (10%)**	**85**	**92**	**80**
W1a	45	24 (53%)	4 (9%)	80	96	100
W1	54	28 (52%)	6 (11%)	72	75	67

**Seismicity recorded between 26/08/96 and 20/10/96*

***Blasting time: 12:00 to 20:00*

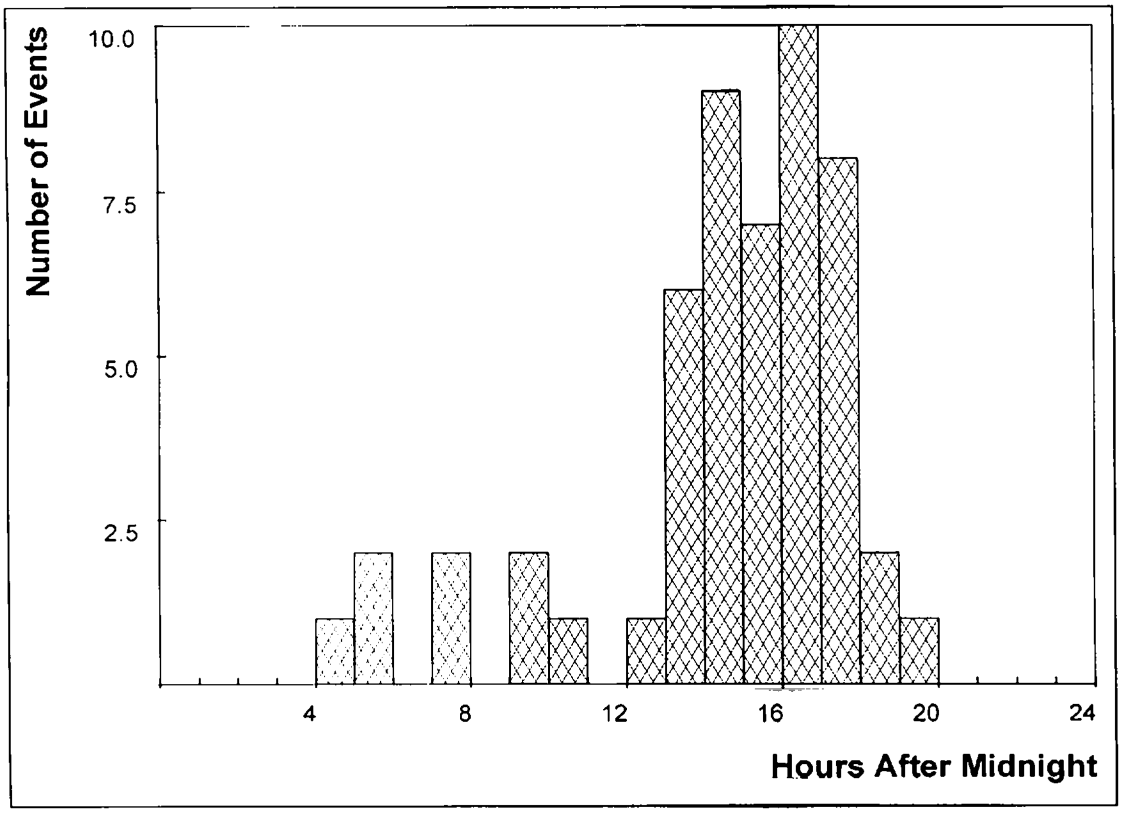


Figure 4-34: Diurnal distribution of seismic data recorded from WDLS 87-49 W3 panel between 26/08/96 and 20/10/96 by Preconditioning PSS.

Note absence of seismic activity between 20:00 and 04:00.

Certain source parameters determined for the seismic data recorded during the period indicate that the preconditioning of W3 panel was having a positive effect on the conditions of that panel compared with those of the other two panels in 87-49W stope. These parameters are summarised in Table 4-6. The higher value for the seismic attenuation parameter κ for the W3 seismicity indicates that the rock mass ahead of the panel face was in a more effectively fractured condition, so that the influence of the fractured (destressed) zone was greater. This conclusion is supported by the higher values for the P-wave to S-wave seismic moment (M_0) ratios for W3, indicating a greater component of crushing of the rock mass ahead of the panel face in the generation of seismic events. Three parameters related to stress drop (Rv_{max}, ρRa and τ_S) all have lower values for W3 than for the control panel (W1a), suggesting that the rock mass ahead of W3 was less highly stressed than that ahead of W1a.

Unfortunately, insufficient seismic data were recorded from W3 panel during the period to allow for discrimination among the different phases of the optimisation study.

Table 4-6: Summary of Seismic Data Recorded During WDLS Preconditioning Optimisation Study*.

Parameters used are described in text.

	M_{min}	b Value	Number	κ (ms)	Rv_{max}	ρRa	τ_S	P/S M_0
87-49W	-0,71	0,64						
W3	**-0,60**	**0,53**	**33**	**0,670**	**0,571**	**7,275**	**5,781**	**1,15**
W1a	-0,79	0,42	27	0,510	0,691	9,066	6,965	0,69
W1	-0,48	0,58	42	0,385	0,487	8,369	5,689	1,09

Seismicity recorded between 26/08/96 and 20/10/96

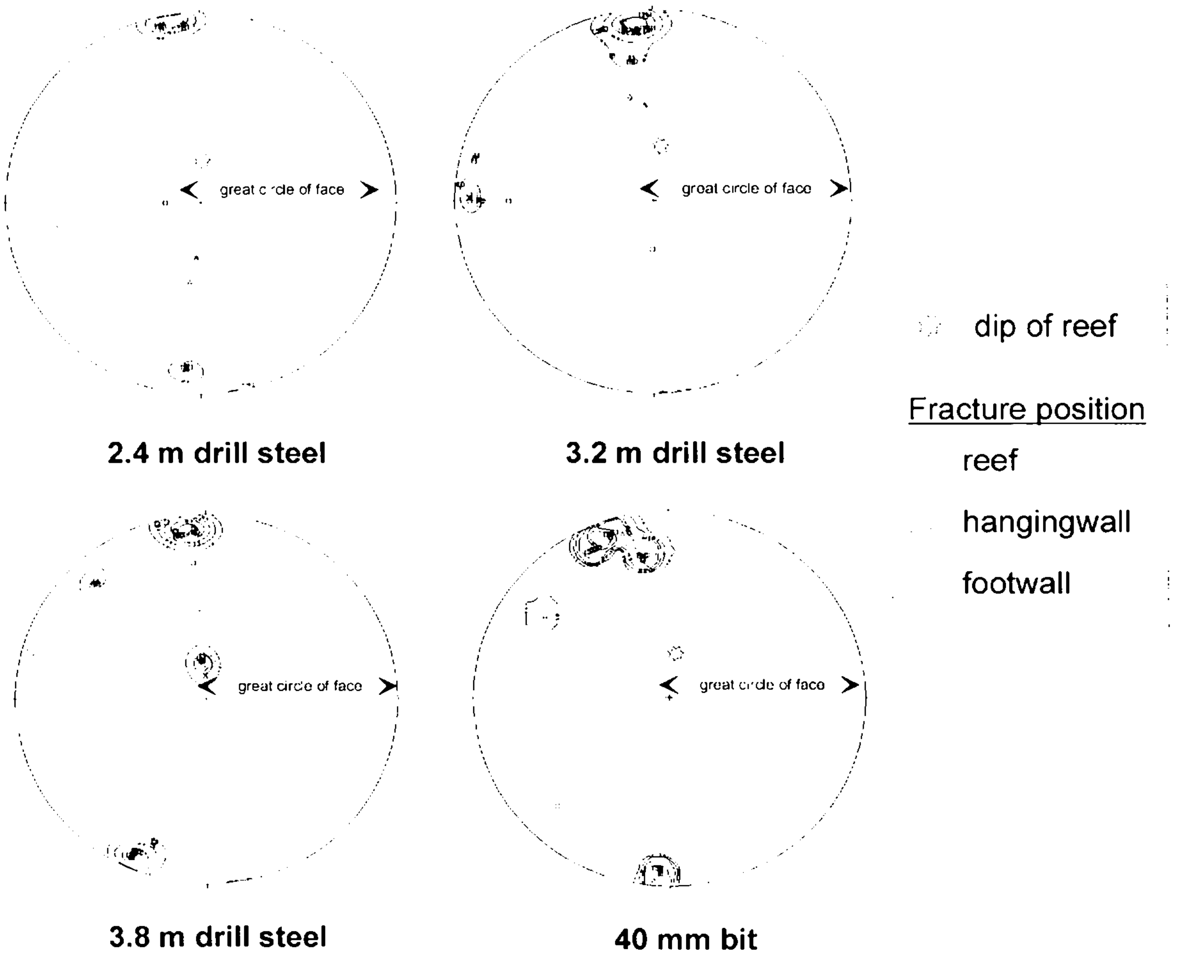
4.4.2.2 Rock mass fracturing

During the optimisation phase, minor variations in the fracture pattern were observed with the various depths of preconditioning and various bit diameters. These differences, while measurable, are less significant than those observed when ground conditions in the preconditioned and unpreconditioned panels are compared. With an increase in drill-steel length, fractures tend to become slightly more shallow dipping, with a decrease in the number of fractures (Figure 4-35). Fractures developed during the use of the 3,8 m drill-steel showed less variation in strike than the ones that formed when a 3,2 m drill-steel was used to drill preconditioning holes (Figure 4-36). This is particularly apparent when the larger 40 mm bit was introduced with the 3,2 m drill-steel. This change is most likely due to the position at which the fractures are remobilized. Owing to greater confinement further ahead of the face, the orientation of σ_2 is limited to a narrower range and hence fracturing is restricted to a more-or-less face parallel orientation. With slightly shorter holes, the blast is not as confined and the fractures that are re-activated can have a greater range in strike orientations, but, once again, these are mainly face parallel.

From the fracture mapping data, it would appear that the 3,2 m drill-steel (with a 40 mm bit) is the most effective at remobilizing the fractured rock mass within the reef horizon, whilst restricting the extent of damage to the hangingwall.

4.4.2.3 Hangingwall profiles

One of the beneficial side effects of preconditioning is an improvement in the quality of the hangingwall conditions. These effects may be quantified by measuring profiles of the hangingwall. With increasing drill-steel length, and subsequent change in bit diameter, the quality of the hangingwall was seen to improve.



2.4 m drill steel

3.2 m drill steel

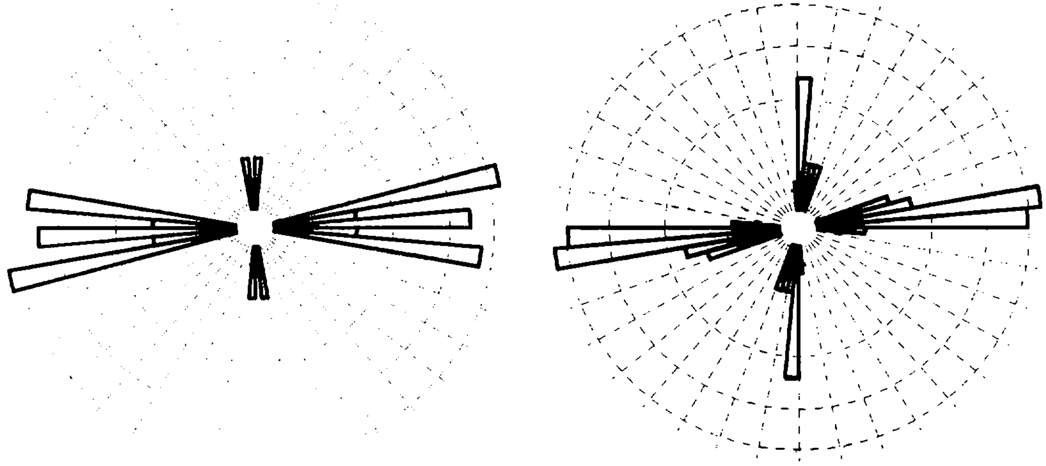
3.8 m drill steel

40 mm bit

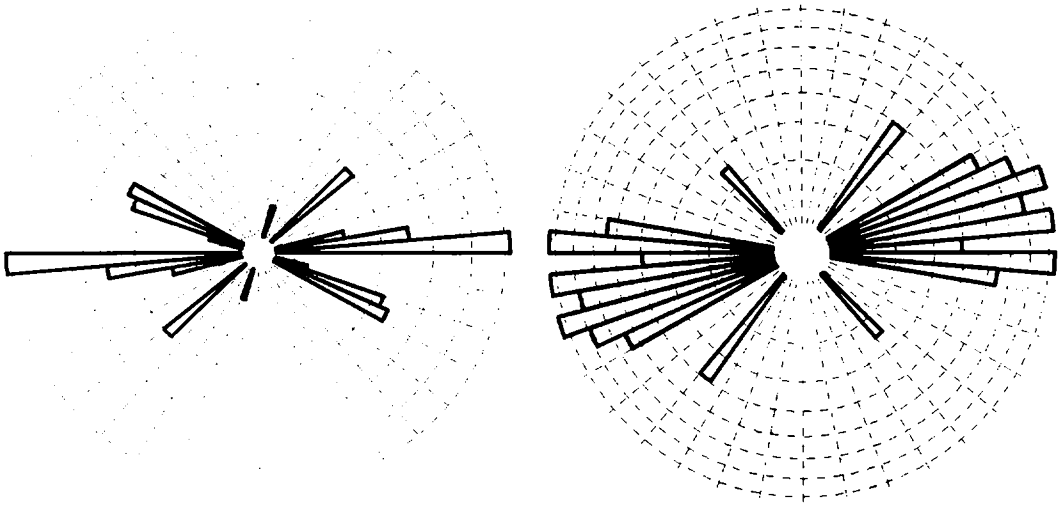
Figure 4-35: Schmidt-net (lower hemisphere projection) of poles to all fractures mapped during the optimisation phase.

Figure 4-37 shows that both the gradient and profile length decreased, indicating a smoother and, hence, better quality hangingwall. The smoother hangingwall results from the combined effect of fewer fractures in the hangingwall and of decreased penetration of those that do occur, compared with unpreconditioned areas.

Profiling was also used to examine the changes in hangingwall conditions between adjacent preconditioning holes. Several short profiles were measured between 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 holes, but even the roughest areas (that is, poorest hangingwall conditions) between the preconditioning sockets were significantly smoother than in unpreconditioned areas (Figure 4-38). This suggests that the preconditioning holes could be spaced slightly further apart; however, practical underground constraints (i.e. support spacing) oppose this.



2.4 m drill steel **3.2 m drill steel**



3.8 m drill steel **40 mm bit**

Figure 4-36: Rose diagrams showing orientation of fractures mapped during the optimisation phase.

Note the increase in the variability of the orientation of fractures in the shorter drill-steel lengths (especially with the 40 mm bit).

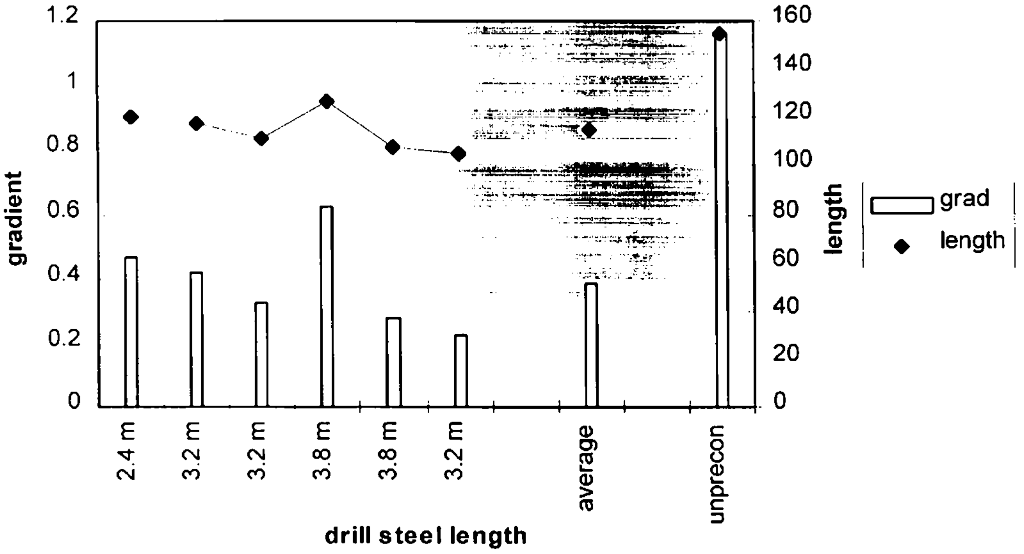


Figure 4-37: Gradient and profile lengths measured during the optimisation phase.

Note the overall decrease in profile length and gradient indicating an improved hangingwall compared with an unpreconditioned panel (the results for the 3,8 m drill-steel are erratic). The last entry for a 3,2 m drill-steel is for the results obtained with a 40 mm drill-bit.

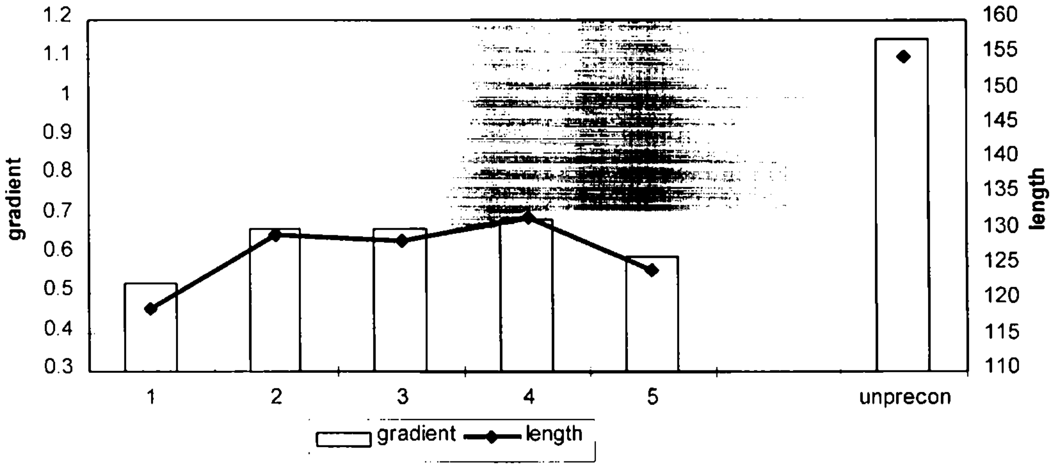


Figure 4-38: Variation in profile length and gradient between preconditioning holes.

Profiles are spaced 0,5 m apart, with profiles 1 and 5 positioned over the previous day's preconditioning socket. This shows that the hangingwall conditions are best immediately above the preconditioning hole, although the entire area is still significantly better than in an unpreconditioned panel. This method of evaluation will be used to investigate the effects of hole spacing

4.4.2.4 Ground penetrating radar surveys

Ground penetrating radar (GPR) was used to determine the effect of preconditioning on the rock mass. The electro-magnetic pulse emitted by the GPR 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 also compared with that ahead of an unpreconditioned face.

Table 4-7 shows the various range settings used during the GPR work and the approximate depths to which these are equivalent. It should be noted that, the deeper the penetration of the scan, the lower the degree of resolution; hence, there is a need to perform several scans at different range settings per survey.

Table 4-7: Range settings with approximate depth of penetration for ground penetrating radar surveys.

Range (ns)	Depth (m)	No. of Scans
35	1,75	3
50	2,5	7
70	3,5	8
100	5,0	1
150	8,0	6

The GPR work proved very successful in delineating the extent of re-activation of fractures ahead of a preconditioned face. Figure 4-39 and Figure 4-40 show annotated radar scans (superimposed with the positions of mapped preconditioning holes) and 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 extends for about 2 m along the stope face. A spacing of greater than 4 m between adjacent holes resulted in an unpreconditioned zone between two preconditioning holes (Figure 4-39). Figure 4-40 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.

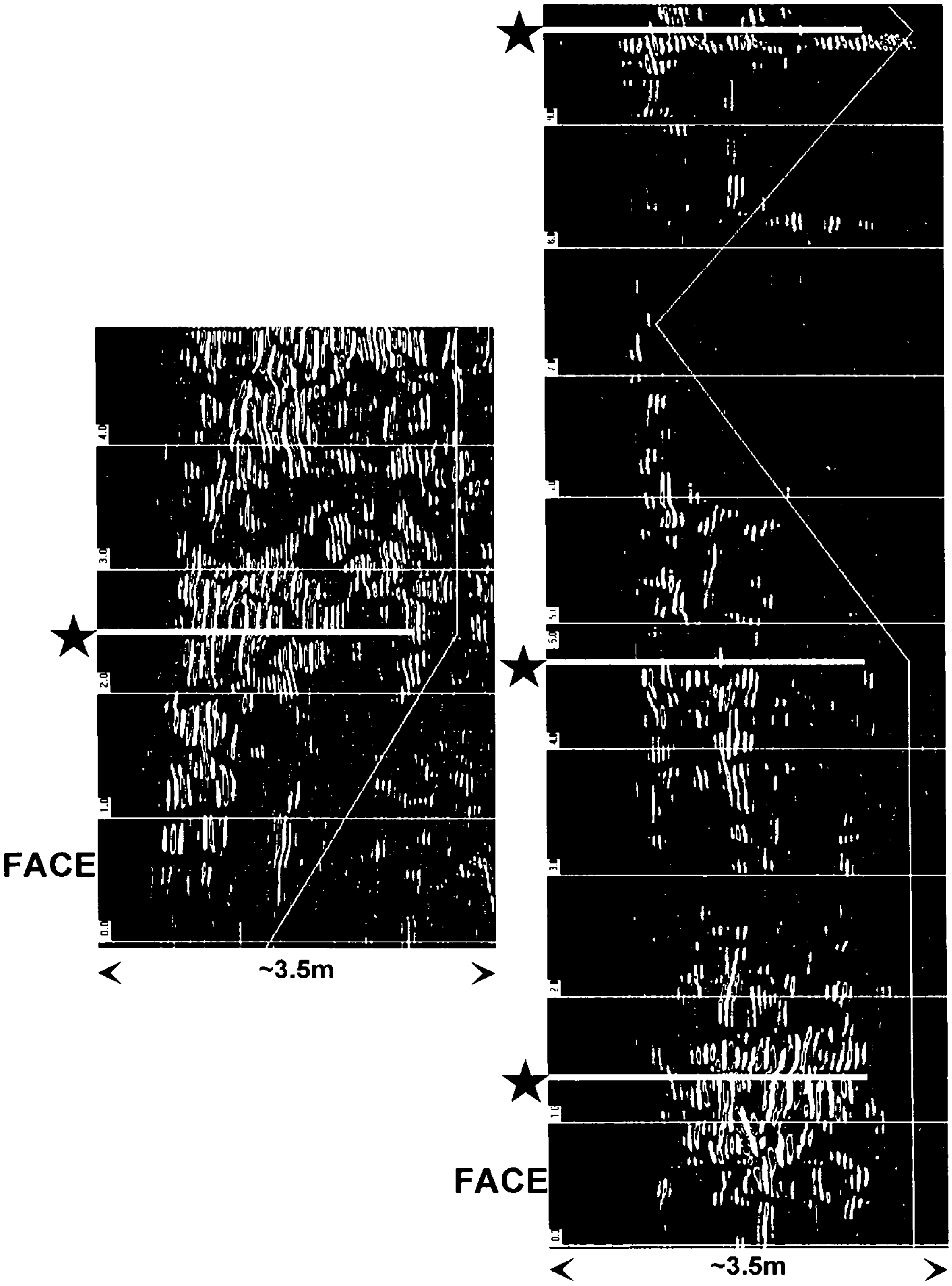


Figure 4-39: Ground penetrating radar scan (range setting of 70 ns).

The solid white bars (and solid stars) represent the positions of preconditioning holes. Note the zone of intensely fractured rock developed around the preconditioning holes.

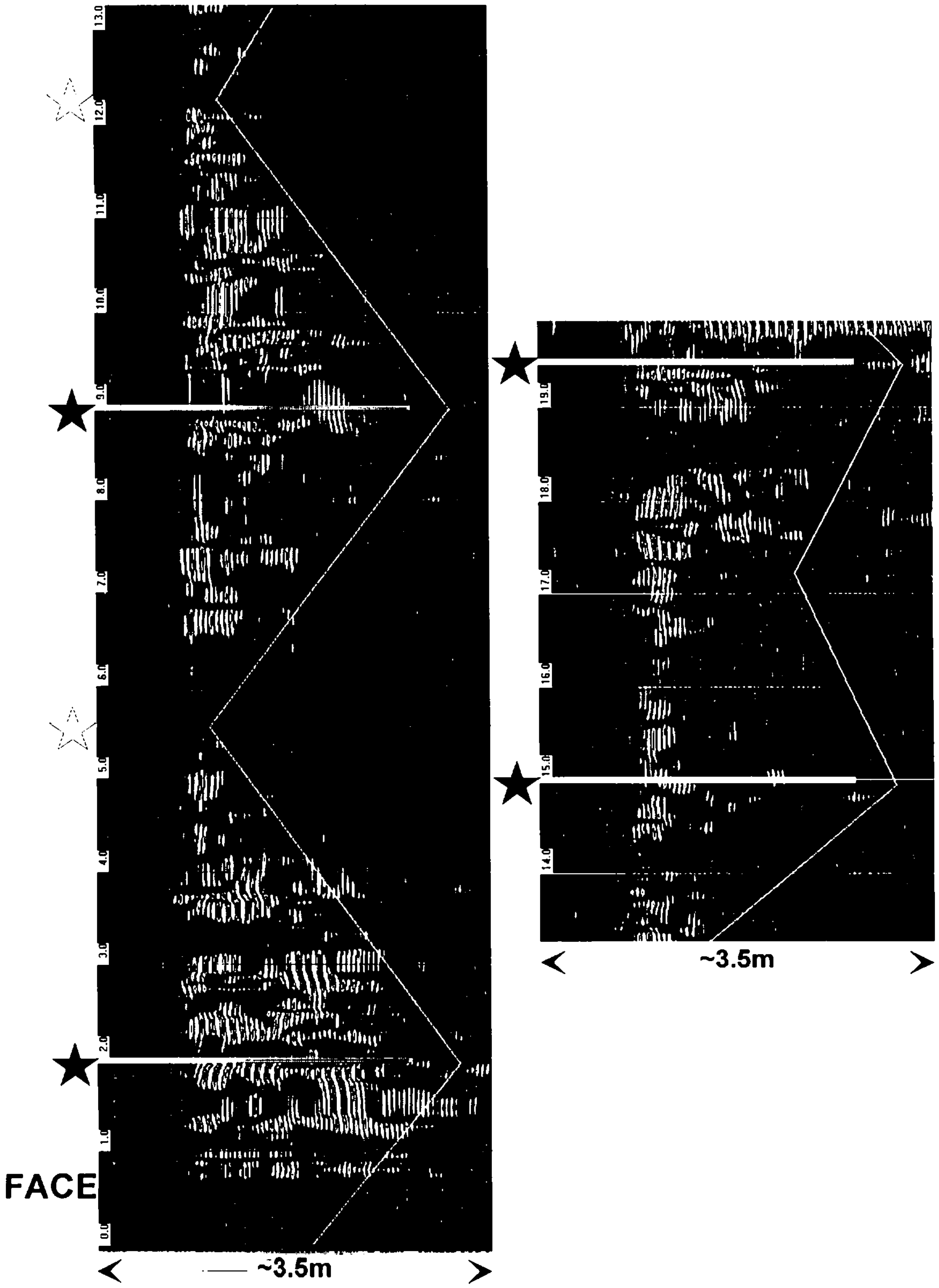
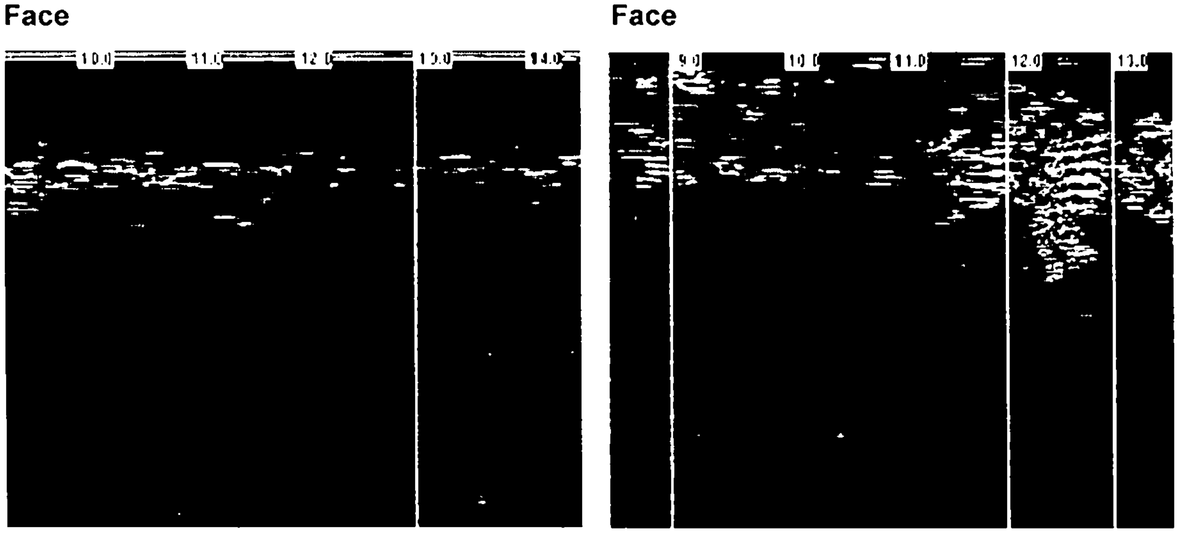


Figure 4-40: Ground penetrating radar scan (range setting of 70 ns).

The solid white bars (and solid stars) represent the positions of preconditioning holes, while the solid grey bars (and hollow stars) show where preconditioning holes should have been drilled, but no such evidence could be found.

A significant difference in the nature of fracturing ahead of preconditioned faces from that ahead of unpreconditioned faces was detected from the GPR scans. In unpreconditioned areas, the depth of open fractures ahead of the face extended to approximately 2,5 m, whereas, in preconditioned areas, the zone of rock ahead of the face with open fractures was up to 4 m deep. The density of open fractures was also much higher in preconditioned areas (Figure 4-41).



(a) **(b)**

Figure 4-41: Ground penetrating radar scan (range setting of 150 ns) of (a) unpreconditioned and (b) preconditioned faces.

There is an increase in both intensity and depth of fracturing in the preconditioned face. The depth of the scan is about 8 m into the face.

4.4.2.5 Convergence data

Convergence/ride stations were installed throughout the period of the preconditioning project on WDLS and this continued during the optimisation programme. A total of six stations were in use during this programme and the convergence recorded during this period has been plotted in Figure 4-42. The ground behaviour recorded for all the stations is consistent, with a high initial convergence rate and then a steadily decreasing convergence rate with increasing distance to face. No significant change in convergence can be noted that would correspond to the change from one preconditioning scenario to another.

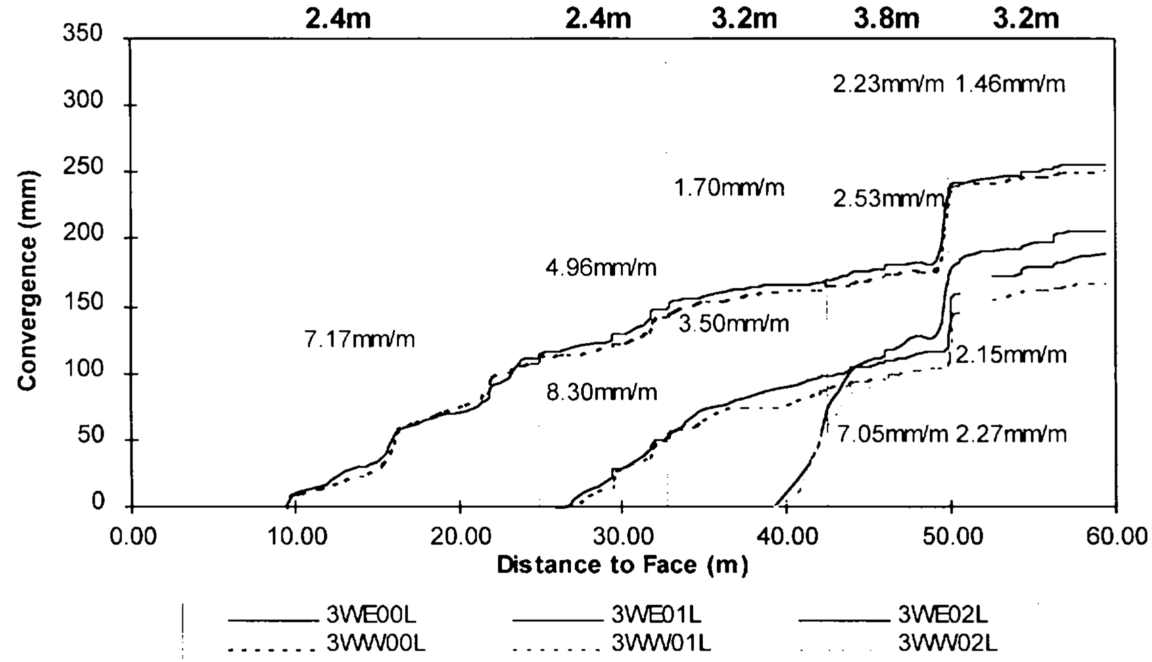


Figure 4-42: Convergence measurements in the test panel (rates in mm/m face advance).

The high convergence noted at 50 m distance to face (5 October) was the result of the two large seismic events shown in Figure 4-33. The change to 3,2 m drill-steels and 40 mm bits was made after these large events. No significant variation can be detected between the different preconditioning scenarios.

4.4.2.6 Face advance

In addition to the safety aspects of preconditioning, a significant increase in the face advance rate, consistent with the improved fragmentation noted earlier, has also been noted. This is mainly due to opening and extending the pre-existing fractures in the reef by 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 contribute to the ease of face breaking. During the optimisation work, the face advances were measured daily at the test panel from fixed points (e.g. a convergence/ride station). The results of these measurements are summarised in Table 4-8.

The effect of preconditioning on face advance rates appears to be significant. The greatest face advance was achieved when the preconditioning holes were drilled with a 3,2 m drill-steel and 36 mm bit. During preconditioning, the average face advance rate increased by almost 50 per cent compared with unpreconditioned periods, which decreased the mining cost per centare. The direct cost of preconditioning is of the order of R6/ca, but a stoping cost saving in excess of R60/ca can be realised under these conditions (Lightfoot et al, 1996).

Table 4-8: Comparison of face advance rates in adjacent panels in the 87-49 stope.

The large maximum face advances were probably the result of extensive barring of the face. The optimum face advance was achieved with 3,2 m drill-steels.

Scenario*	No. Points	Face advance (metres per blast)		
		Minimum	Average	Maximum
Unpreconditioned	30	0,55	0,70	0,85
Preconditioning (2,4 m, 36 mm)	20	0,80	1,06	1,60
Preconditioning (3,2 m, 36 mm)	8	0,80	1,16	1,50
Preconditioning (3,8 m, 36 mm)	6	0,90	1,14	1,35
Preconditioning (3,2 m, 40 mm)	7	0,90	1,03	1,20

preconditioning holes described by drill-steel length and bit diameter

4.4.2.7 Drilling rates

The drilling rate should be affected by the state of stress in the rock. The initial study during 1995 into the time required to drill one 3,0 m long preconditioning hole established that the average drilling time was 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 machine operator and an assistant) were allocated to drill about 60 production holes in total. Since six preconditioning holes should be drilled in such a panel, it was thought that each drill crew would need to drill for an extra 45 minutes. Thus, when preconditioning was initiated on a particular panel, it was considered, among the workers, as work in addition to their daily responsibilities.

The timing of the drilling of both preconditioning and production holes was undertaken at the test panel. The results of these timing studies are tabulated in Table 4-9 and Table 4-10. As the hole length increased, so did the drilling time (Table 4-9). However, this increase was not uniform. It took one minute longer to drill 3,0 m holes than 2,2 m holes (an extra 0,8 m) and two minutes longer to drill 3,6 m holes than 3,0 m holes (0,6 m extra). 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 drill-steel and 40 mm drill-bit. Although the area to be drilled was increased by 23 per cent, the additional button on the 40 mm 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 3,6 m was not an impossible task and could be completed in less than 15 minutes.

Table 4-9: Comparison of drilling rates of preconditioning holes.

The rapid drilling with a 40 mm drill-bit is due to the improved efficiency from one additional button on the bit.

Scenario*	No. of Points	Min	Average	Max	Average (metre/minute)
Preconditioning (2,4 m, 36 mm)	11	10'00"	11'38"	12'59"	0,19
Preconditioning (3,2 m, 36 mm)	12	10'30"	12'37"	14'16"	0,24
Preconditioning (3,8 m, 36 mm)	13	12'59"	14'31"	15'55"	0,25
Preconditioning (3,2 m, 40 mm)	16	8'36"	10'45"	12'35"	0,28

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

The effect of preconditioning on improving the drilling rate of production holes is significant (Table 4-10). This has a favourable impact on the actual time the drilling team spends in a shift. All of the preconditioning scenarios have higher drilling rates than the unpreconditioned case, the best drilling rate being 0,36 m/min. If the total drilling times are compared in unpreconditioned and preconditioned panels, it can be seen that less time is actually spent drilling in preconditioned panels, despite drilling more metres (Figure 4-43).

Table 4-10: Comparison of drilling rates of production holes for adjacent preconditioned and unpreconditioned panels.

Drilling times decrease with increased drill-steel length and drill-bit diameter.

Scenario*	No. of Points	Min	Average	Max	Average (metre/minute)
Unpreconditioned	28	4'34"	5'08"	5'51"	0,21
Preconditioning (2,4 m, 36 mm)	6	3'56"	4'48"	5'50"	0,23
Preconditioning (3,2 m, 36 mm)	8	3'00"	3'57"	5'10"	0,28
Preconditioning (3,8 m, 36 mm)	11	2'30"	3'05"	3'55"	0,36
Preconditioning (3,2 m, 40 mm)	14	1'56"	3'14"	4'31"	0,34

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

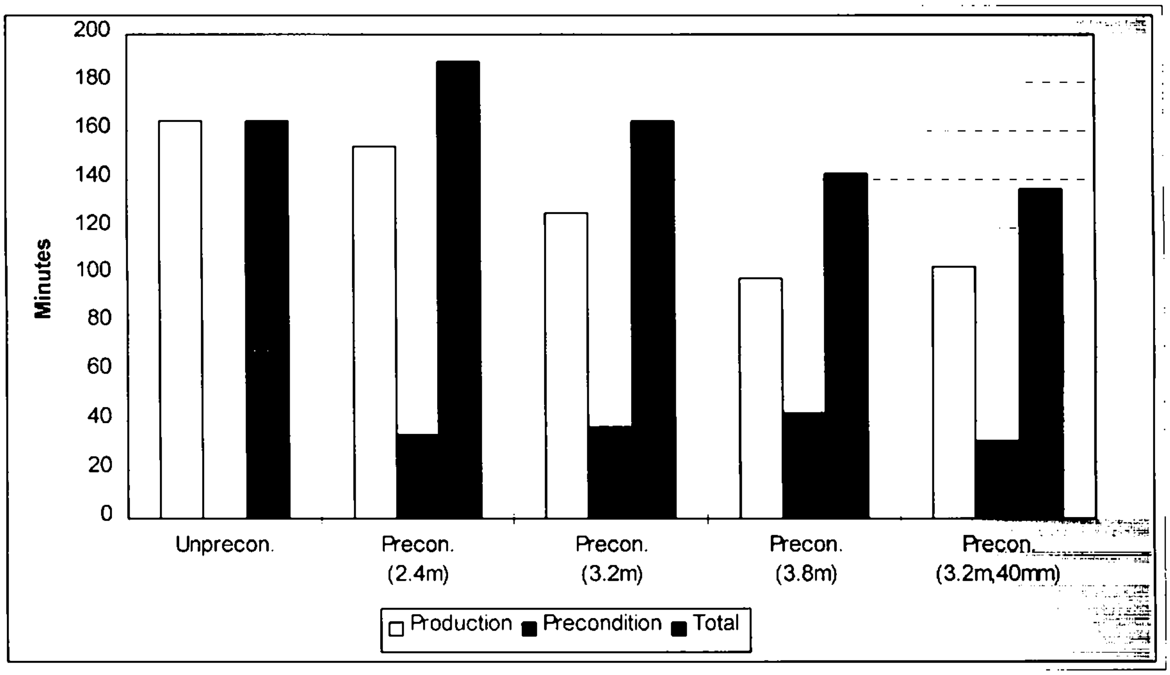


Figure 4-43: Actual drill times spent to drill 32 production and three preconditioning holes (which represents the average number of holes per crew).

4.4.3 Guidelines for face-perpendicular preconditioning

Guidelines for the use of short, small diameter, face-perpendicular holes for the preconditioning of production stope faces on ultra-deep longwalls were developed from the research findings detailed above, and are attached to this report as Appendix 3.

4.5 Enabling output 3: Implementation of preconditioning

Preliminary training exercises have been carried out on Elandsrand and on Western Deep Levels South Mines at the request of mine management. Elandsrand began preconditioning in early May 1996, with considerable success being reported. Several days of face bursting in the geologically complex area of the 80-35 ledge prompted the mine to investigate the use of preconditioning. After the introduction of face-perpendicular preconditioning in early May, no rockburst damage of any kind was reported. Several visits were made to the site, to investigate the method of implementation and its results. It was found that preconditioning was not routinely carried out and this was immediately reflected in the condition of the hangingwall. The results were discussed with all production personnel involved. A discussion session in the training centre with the entire stope crew on the use of preconditioning proved extremely useful in the mutual understanding of the issues surrounding its implementation, even though similar discussions had been held at the face.

Owing to the greater extent of interest in and usage of preconditioning at WDLS, a broader approach was taken for the technology transfer and implementation of the technique. Training sessions were conducted with all safety officers and training centre personnel, to make them aware of the technique, basic theory, benefits and how to evaluate the effectiveness of these blasts quickly from the effects on the production face. While adequate training took place at this recent project site, the education was delayed, and therefore the preconception that preconditioning represents extra work could not be changed in the attitudes of the workforce. Payment for this supposed extra work became an issue which led to the preconditioning being discontinued when the project team was withdrawn from the site.

In order to ensure that preconditioning will continue in the appropriate manner, it has 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. Appendix 4 contains an example of how either of the preconditioning techniques could be included into a mine's current standards. Detail is provided on how the preconditioning holes are to be drilled, charged and blasted in conjunction with production holes.

4.5.1 A structured implementation process

A training scheme for the implementation of preconditioning has been developed out of experience gained at research sites and in assisting with pilot implementation programmes on individual mines, as well as from responses to a worker attitude survey, and has been tested in practice. This training scheme provides for all affected personnel, including management, training centre staff and safety officials, and all levels of the production workforce (from management to face crews). Instruction is conducted both on surface and underground. Mine training staff must be included in the process, so that they can continue the training after the introductory implementation period; similarly, safety personnel must be included, so that they can follow up on the application of preconditioning at underground sites.

It is considered essential to educate the workforce 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 with them, and then providing preconditioning as part of the solution. This is preferable to a top-down approach whereby preconditioning is simply added to their work-load without their 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.

It is important to dispel the notion that preconditioning is simply extra work for them at the outset. No separate bonus payment should be necessary, as an extra production bonus is indicated for extra face advance brought about by effective preconditioning. 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.

When training the workforce underground, it is important to be able to substantiate any claims made for the benefits of preconditioning. This could be effected by measuring the face advance before and after the introduction of preconditioning (through evaluation of survey plans); a lack of production hole sockets in the face after a blast with preconditioning is also a useful indicator. The reality of the increased production bonus could thus be established. Similarly, timing the drilling operation carefully will allow for the demonstration 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.

4.5.2 Education and training

Education and training are divided into sections, as follows:

- Introduction
  - The face burst problem: what it is, how it arises and what the effects might be
  - 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 (longwalls, sequential grid)
  - Face-parallel preconditioning: special areas (remnants, pillars)
- Implementing preconditioning
  - The importance of correct application
- Assessing the effectiveness of preconditioning
  - Tools available for making the assessment

The level of detail and specific emphases in each section would obviously vary according to the audience (e.g. whether face crew or management). The face 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.

The education and training scheme is detailed in Appendix 5.

4.5.3 Implementation sites

The preconditioning research team was involved in implementation on various mines, in order to learn more about the feasibility of providing an implementation team as well as the other issues associated with the process. Twelve letters advertising preconditioning were sent to managers of various gold mines and three prompt responses were received. Soon thereafter, the implementation process was initiated by holding seminars at these interested mines, to which the management teams were invited. In addition to the management teams, the mines' production and rock mechanics department personnel attended the seminars and also showed a positive attitude towards preconditioning. The outcomes of these seminars are summarised below, in the order in which the responses were received.

4.5.3.1 Mine A

The seminar was well received and very effective in creating an environment for discussion of the possibilities of implementing preconditioning at this mine. The mine has been experiencing difficulties when mining in the vicinity of seismically active geological features, such as faults and dykes. While the problematic areas are mainly remnants, the difficulty of integrating face-parallel preconditioning into the production cycle meant that the attendees were more interested in attempting to apply face-perpendicular preconditioning to the remnant areas. Although it is believed that face-perpendicular preconditioning should have some effect, even in such secondary mining environments, this has not been investigated by the preconditioning project team, so the issue still remains unsettled. Another interesting question related to the direct application of preconditioning to seismically active geological features, rather than to the stope faces. Previous experience at a face-perpendicular preconditioning site has shown that face preconditioning can help to minimise the damage caused by seismicity located on geological discontinuities in the vicinity of the mining face, but the project team has not investigated preconditioning such features directly. Therefore, it was recommended that preconditioning be used on the faces, to minimise the damage caused by seismicity associated with the geological features, as well as to prevent face bursts caused by high face stresses.

The mine management decided to reconsider the possibility of implementing preconditioning on this mine and will contact the preconditioning project team if further assistance is required. However, no contact has been made since then.

4.5.3.2 Mine B

As with 'Mine A', the seminar was very effective in creating a fruitful discussion session and a positive attitude towards preconditioning. The majority of this mine's production comes from secondary mining (pillar extraction) areas, due to very limited ground being available for primary mining. Thus, face-parallel preconditioning would be most beneficial and was recommended for minimising the face burst risk associated with pillar extraction. However, as with 'Mine A', the management team of this mine was more interested in face-perpendicular preconditioning and the possibility of implementing it in a pillar extraction environment. Personnel from both 'Mine A' and 'Mine B' resisted implementing face-parallel preconditioning, due to the difficulty of fitting it into the mining cycle. A related reason for being more interested in face-perpendicular preconditioning was that the effect of increasing the face advance rate has been quantified for this method. Although there is no reason that face-parallel preconditioning should not have a similar effect on face advance rate (considered per production blast), this has not been quantified.

Following the seminar, mine management and the rock mechanics department decided to implement face-perpendicular preconditioning in two different pillar extraction areas, with very limited involvement of the preconditioning project team. Some time after the actual implementation was initiated by mine personnel, the rock mechanics department reported that preconditioning was implemented successfully at one site; the project team's involvement was required at the other site. The site was visited by the project team together with production and rock mechanics personnel.

At this site, there are a series of dip pillars which were left behind after sequential grid mining took place between two faults (Figure 4-44). The fault located at the upper boundary of the dip pillars is seismically very active and has historically caused damaging events. The other fault (situated at the down-dip boundary) is seismically inactive, probably because the down-dip side of the fault is still unmined. The intention was to mine these dip pillars one at a time, reducing the hazard by using face-perpendicular preconditioning and by leaving bracket pillars at both the up-dip and down-dip ends of each dip pillar. The mining activity had been carried out by advancing a breast panel through the pillar, with a gully on the down-dip side of the face (Figure 4-44). Although the physical conditions of the face and hangingwall were satisfactory at the time of the first visit, the preconditioning project team expressed concern about breast mining under those conditions.

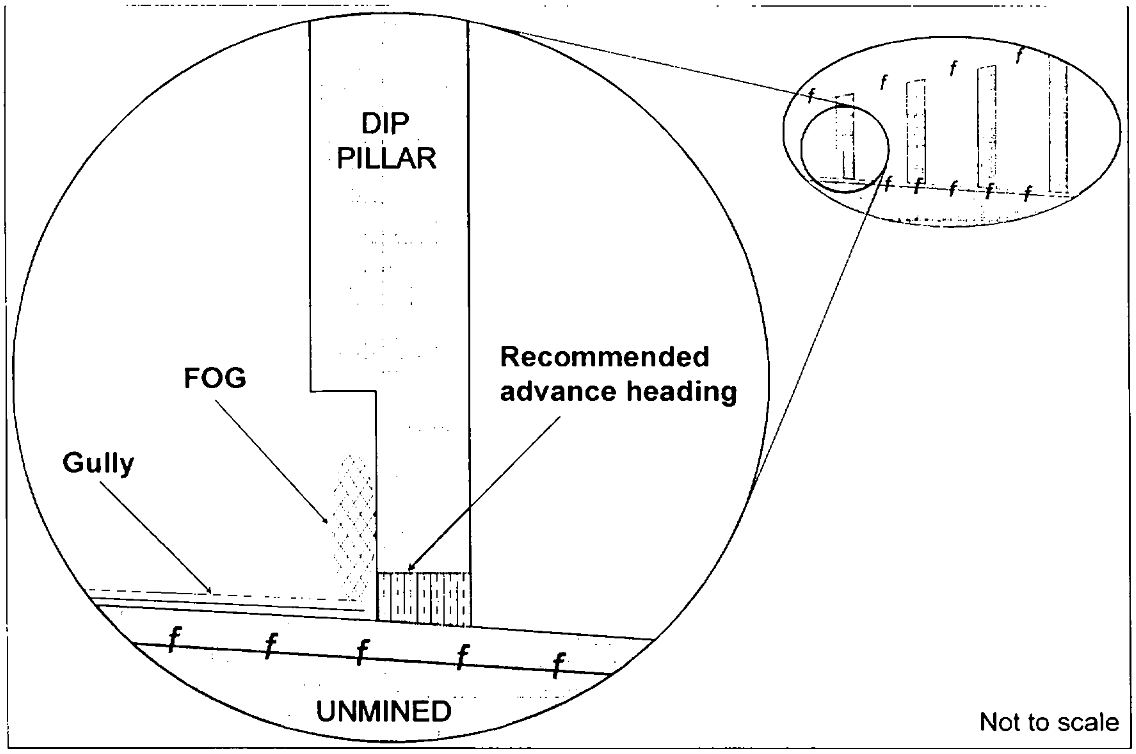


Figure 4-44: Implementation site B.

The site was visited a second time a few days after the first visit and extensive falls of ground in the face area were observed (Figure 4-44); these had occurred a few days earlier. This confirmed the concerns of the preconditioning project team about the breast mining. It was recommended that the advancing breast panel be stopped and a wide (~10 m) advance heading be mined together with the gully. The mining of up-dip panels should be started once the advance heading holes through. It was also suggested that implementing preconditioning on the breast panel would probably help to improve the situation, but would not solve the problem, which was directly related to the mining configuration.

The mine's rock mechanics department, together with production personnel, decided to review the recommendations of the preconditioning project team and to make contact if assistance is required, but to date the project team has not been contacted.

4.5.3.3 Mine C

As with the previous seminars at the other mines, this seminar was very successful in the sense of generating a beneficial discussion for both parties and attendees expressed a positive attitude towards preconditioning.

Following the seminar, mine management decided to implement face-perpendicular preconditioning, on a trial basis, at one of the face burst-prone sites on the mine and invited the preconditioning project team to take part in the initial implementation process. The site (Figure 4-45) was visited by the project team, together with the production personnel. Panels I and II have experienced high face stresses with resultant face bursts, because of the long lead-lag distances associated with the early stages of cutting a stabilising pillar. In addition to the face burst problem, hangingwall fall-outs associated with face-parallel shallow dipping (~20° towards face) and steeply dipping (>70° away from face) fracture sets were quite common in the face area. The site was well suited to the implementation of face-perpendicular preconditioning in order to apply the current knowledge and also to learn more about implementation issues. The production personnel, although they have had only minimal exposure to preconditioning, have shown interest and appear to be enthusiastic to use preconditioning immediately as an aid to solving their problems at the site.

A separate seminar for shift bosses and some rock mechanics practitioners was held, during which more practical issues were discussed. The seminar was very effective in generating interest and discussion, but some concerns were expressed by one rock mechanics practitioner who had briefly been involved with preconditioning at another mine. At that mine, an attempt had been made to implement preconditioning without consulting the preconditioning project team and the claim was made that preconditioning was "not effective". The project team had become involved at that site at a later stage of implementation and found that the preconditioning was being incorrectly applied; neither education nor training had been provided for the stope crew. It was also very difficult to change the stope crew's preconceptions about preconditioning at that stage. Nevertheless, some progress had been made in some parts of that site in teaching the correct application of preconditioning; however, some time later, mine management had decided to discontinue the preconditioning. The seminar and subsequent discussions were apparently not effective in changing the preconceptions of that individual.

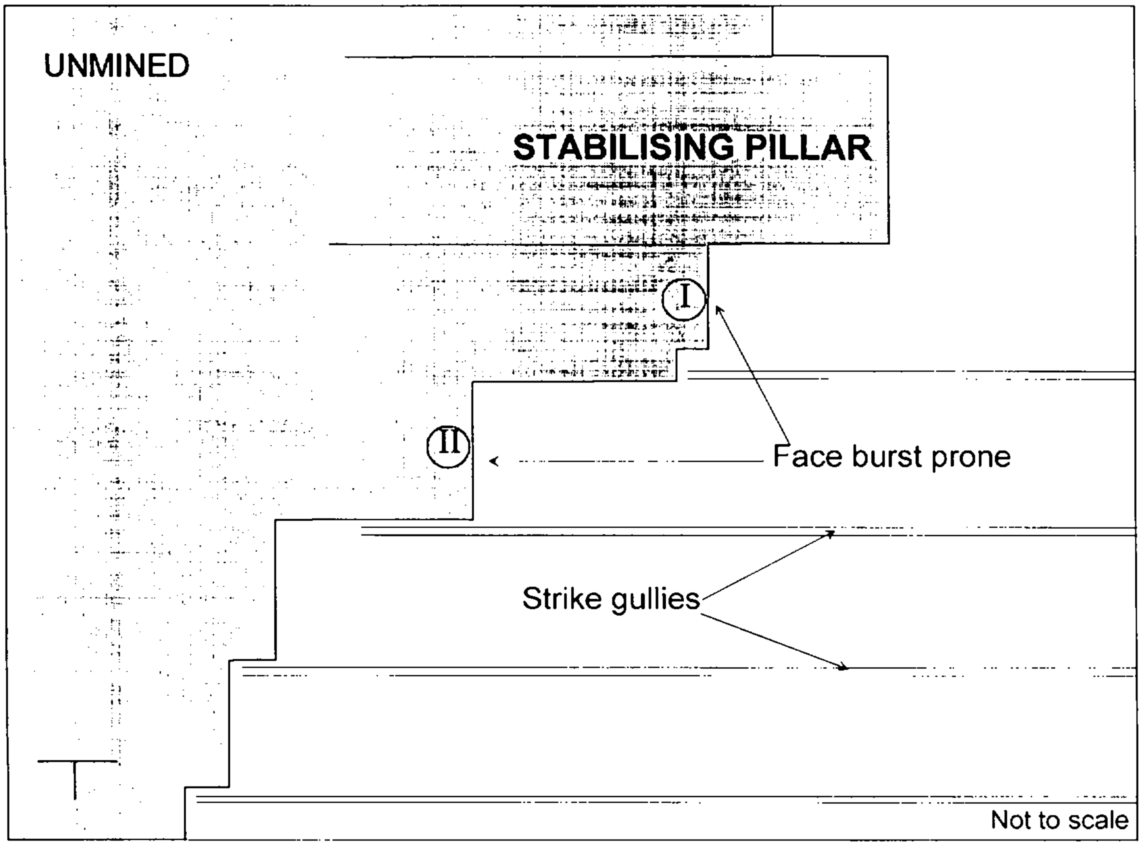


Figure 4-45: Implementation site C.

While the implementation process at 'Mine C' seemed to be progressing and the preconditioning project team was preparing for another training session for the stope crew, there were some changes in the management structure of this mine. Ultimately, while the new mine management was apparently in favour of the implementation of preconditioning at this mine, it was decided to postpone the preconditioning activity.

4.5.3.4 Mine D

This mine's rock mechanics department implemented face-perpendicular preconditioning in one of their problematic areas. The intention was to minimise the occurrence of and damage caused by face bursts associated with foundation failure at the south side of stabilising pillars (Figure 4-46). The preconditioning project team was invited to hold a technical discussion, rather than to be involved in the implementation. During the discussions, it was stated that, since face-perpendicular preconditioning had been initiated, a substantial reduction in the number of face bursts and the resulting production losses had been found. The site had experienced a number of large damaging seismic events, but the damage was concentrated in non-preconditioned areas (Figure 4-46). As this is an unusual application of preconditioning, the project team requested that they be allowed to study it in greater detail. It is especially important to learn how the effects of preconditioning carried out a few months earlier (furthest away from the panel face) can still be manifested. This would seem to contradict the time-dependent nature of the preconditioning effect (although the fact that the edge of the pillar is stationary might have a bearing on the apparently greater permanence of the preconditioning effect). The mine's rock mechanics department is to contact the project team to initiate further study at this site.

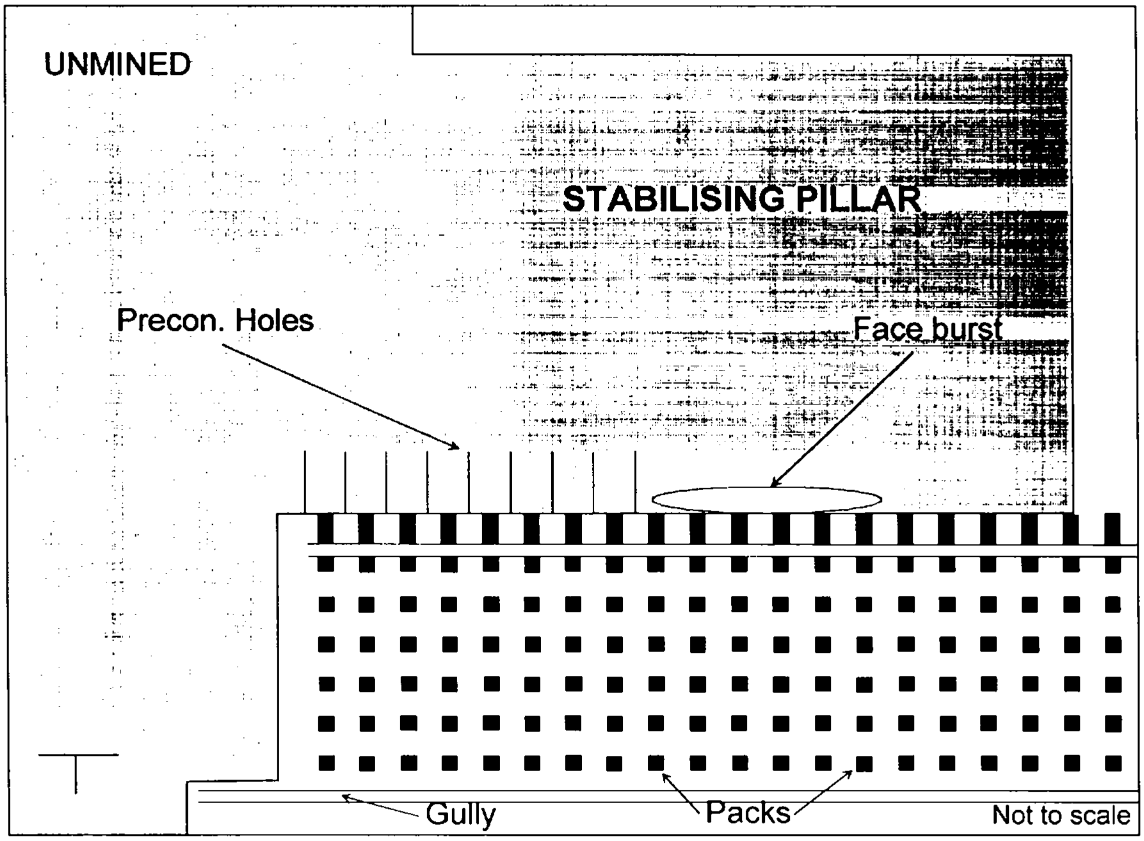


Figure 4-46: Implementation site D.

4.5.3.5 Mine E

This mine invited the preconditioning project team for an underground visit to a mechanical mining site and to discuss the possibilities of using preconditioning at that site. There was no face burst problem at the site, but the impact ripper was having difficulties breaking the hard footwall quartzite. In addition, the workers at the site were experiencing a hangingwall control problem. The idea was to set off regular tailored preconditioning blasts to increase the face advance rate and to improve hangingwall stability.

Since a preconditioning blast is usually set off in a fractured medium, the predominant mechanism of preconditioning is then one of stress transferral by remobilizing the pre-existing fractures around the blast hole. Some new blast-induced fracturing has been observed in the vicinity of preconditioning holes, but these were confined to the reef horizon and never extended beyond the hangingwall-reef contact. If a preconditioning blast is set off in a fairly massive, less fractured medium, more blast-induced fracturing might be expected. Thus, the shattering effect of the blast could be used to overcome the problems being experienced at this site. The project will be initiated in the near future.

5 Conclusions and recommendations

5.1 Conclusions

5.1.1 Preconditioning techniques

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

Face-parallel preconditioning seems to be the more effective method from a rock mechanics point of view: the very pronounced strain energy release and stress transfer evident from the seismic data and the significant convergence recorded after face-parallel preconditioning blasts are both not as evident in the data recorded in association with face-perpendicular preconditioning. While face-parallel preconditioning is currently the recommended method for pillar extraction, its implementation can be difficult under many circumstances, due to the practical limitations of this method. The need for special drilling equipment, a separate drill crew and access ahead of the panel to drill the holes all hinder the application of face-parallel preconditioning. In special areas, however, this may be the only way of safely extracting highly stressed ground and it appears to be an effective method for pillar extraction.

Owing to the difficulty of incorporating face-parallel preconditioning within the mining cycle, there seems to be resistance to using face-parallel preconditioning, even for pillar extraction. The implementation of face-perpendicular preconditioning is commonly considered to be more attractive, since it is easier to fit into the mining cycle and the side-effect of improving face advance rates has been quantified. Face-perpendicular preconditioning can more easily be applied routinely, without undue concern for panel sequencing and for correct positioning of the preconditioning holes ahead of the face. The face-perpendicular method also does not suffer from the potential adverse effects arising from the need for a substantial length of stemming (which is not removed by the subsequent production blast).

However, face-perpendicular preconditioning is also not without stringent requirements. The most important of these is the dependence of this method on adhering to a strict firing sequence. Out-of-sequence initiation could lead to misfires or to the preconditioning blast's breaking rock, rather than preconditioning it. It is vital that all preconditioning holes initiate, because, if one hole is not blasted (due to a misfire or due to not being drilled at all) and all of the other holes are blasted, this one area could become a stress concentrator by accepting the transferred load from the preconditioned areas.

When preconditioning a stope face, the siding and lead area between panels must not be ignored; they are also susceptible to bursting. This was addressed with respect to face-parallel preconditioning, to some extent, when the long holes were drilled longer than the face to extend into the adjacent panels. Preconditioning holes need to be drilled into these susceptible areas when the face-perpendicular technique is used.

5.1.2 Preconditioning mechanism

The effect of preconditioning is localised both in space and time. As the mechanism of preconditioning is one of stress transfer resulting from induced deformations in the fracture zone ahead of the face, rather than one of actually modifying the material properties of the rock, the zone that is preconditioned is still capable of carrying high loads. After a face has been preconditioned, it is possible that subsequent mining of that face or of adjacent faces will result in the transfer of stress back onto the preconditioned rock mass, if nothing is done to prevent this from happening.

Of practical significance is that stress transfer is a dynamic, ongoing process. The stress is redistributed in the rock mass in response to both mining and preconditioning. The preconditioning process must be integrated into the production cycle in a controlled, sequential manner. This sequence must be engineered to ensure that the most favourable stress distribution for maximum face stability is maintained at all times. In the case of face-parallel preconditioning, this means that the order of preconditioning must be sequential, from the lagging to the leading panel. In the case of face-perpendicular preconditioning, these blasts must be maintained as an integral part of the production blast cycle: every production blast must be accompanied by an effective preconditioning blast.

5.1.3 Safety and productivity

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

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

An improvement in hangingwall stability has generally been noted in preconditioned areas. Fracture mapping results have indicated that a reduction in the prevalence of adversely-oriented fractures was probably the major contributing factor to this improvement. The mechanism of preconditioning is one of opening up pre-existing fractures ahead of the stope face, so as to dissipate strain energy by enhancing shear mobilisation of the discontinuities and the breaking of asperities. In the process, blast gases can also penetrate the distinct bedding plane that overlies many reefs, weakening or even delaminating this plane. Any fractures that have a tendency to grow in the preconditioned zone will not be able to penetrate this weakened bedding plane. Under these circumstances, production blast fractures will truncate before they cause damage to the hangingwall. However, preconditioning experimentation to date has generally taken place in areas with a reasonably strong and competent hangingwall, with a relatively narrow stoping width. It is possible that large preconditioning blasts may have a detrimental effect on the stability of weaker hangingwall strata. It is expected that future implementation of preconditioning in different areas will provide more insight in this regard.

In addition to the safety aspects of preconditioning, a significant increase in the face advance rate, consistent with the improved fragmentation, has also been noted. During preconditioning, the average face advance rate increased by almost 50 per cent compared with unpreconditioned periods, which decreased the mining cost per centare. The direct cost of preconditioning is of the order of R6/ca, but a stoping cost saving in excess of R60/ca can be realised under these conditions.

The effect of preconditioning on improving the drilling rate of production holes was also significant. This has a favourable impact on the actual time the drilling team spends in a shift. When the total drilling times were compared in unpreconditioned and preconditioned panels, it was seen that less time is actually spent drilling in preconditioned panels, despite drilling more metres. Higher drilling rates were achieved when the amount of explosive in the preconditioning holes was increased.

5.1.4 Optimisation of preconditioning

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

When considering drill-steel lengths, optimal results were achieved for preconditioning holes drilled with 3,2 m drill-steels. These drill-steels yielded the best face advances, if only marginally better than those from 3,6 m drill-steels. The latter drill-steels did yield slightly higher drilling rates, but required longer manoeuvring times. The relative practical merits of using the 3,2 m drill-steels in the confined space of a stope face also outweighed whatever improvement in preconditioning effect might have been derived from the longer drill-steels. The use of 2,4 m drill-steels is not recommended, although preconditioning even with the shorter drill-steels is more beneficial than not preconditioning at all.

The use of a larger diameter drill-bit (40 mm, compared with the standard 36 mm bit used for drilling the normal production holes) with the 3,2 m drill-steels yielded somewhat improved results. However, potential practical problems that could be encountered when using drill-bits of two different sizes in the stope may outweigh the potential gains of using the larger bits. Therefore, the use of drill-bits of the same diameter as those used to drill the normal production holes is recommended for drilling the preconditioning holes, to facilitate the successful integration of preconditioning into the production routine.

The final stage in the optimisation study involved the investigation of the effects of changing the spacing between preconditioning holes. Analysis and interpretation of the GPR data indicated that the effective zone around each preconditioning hole extends 2 m along the stope face. Thus, a maximum spacing of 4 m between preconditioning holes is recommended for effective preconditioning of the whole length of the stope face. This should prevent the formation of hard patches of locked-up fractures ahead of the face, which could attract stress concentrations, leading to an increased risk of face bursting. In practice, the spacing between adjacent preconditioning holes is influenced by the spacing between packs at the face, but it is important that this should not be allowed to result in increasing the hole spacing to beyond the recommended maximum.

The seismicity, convergence-ride measurements and fracture-mapping data have contributed to the attainment of valuable insights into the efficacy of preconditioning, when used to compare the characteristics of preconditioned and non-preconditioned areas of the stope. However, these data sets have thus far not revealed significant differences among the results from the use of the various face-perpendicular preconditioning parameters. Similarly, hangingwall profiling has proved to be a very valuable tool in quantifying the improved underground conditions derived from the use of preconditioning, but the results obtained from examination of hangingwall profiles conducted as part of the optimisation study were ambiguous, although they did suggest that the use of larger-diameter drill-bits might provide for more effective preconditioning.

5.1.5 Implementation of preconditioning

Owing to a fundamental lack of understanding of preconditioning, certain mines have been trying to implement preconditioning under inappropriate conditions or to solve problems to which preconditioning is not suited. Therefore, 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. Such an implementation team should consist of at least a project engineer and a technician, i.e. one person who understands the fundamentals of preconditioning and another who is familiar with the practical application and can communicate effectively with the workforce in the underground environment.

The education of all production personnel and the training of the stope crew are essential, although these steps may not be sufficient for successful implementation of preconditioning. 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. In addition, the definition of preconditioning as part of the mine's Code of Practice is required. The example in Appendix 4 could be modified such that it could be incorporated into an existing mine standard.

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, in addition to the safety benefits of preconditioning, the direct and indirect implications in terms of their bonuses must be clearly explained. As a last resort, since preconditioning has been found to be a cost-effective safety measure, some additional safety incentive bonuses may be considered to ensure proper implementation.

5.1.6 Assessment of the effects of preconditioning

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

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

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. The shapes of holes drilled into a preconditioned face should be less elongated, reflecting the reduced stress levels acting on the rock mass ahead of the face.

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

A history of the convergence rates in the stope can facilitate awareness of rock mass response to changing conditions (in terms of such factors as geometry and seismicity). Variations in convergence can provide indications of increasing strain energy being stored ahead of the stope face. Convergence/ride stations provide the actual convergence within the stope, as they can account for the ride components. The profile of these convergence plots is the result of both the geometrical change in the excavation as the face advances and the time-dependent behaviour of the rock mass. The true time-dependent behaviour of the rock can be identified by using convergence instruments (such as clockwork convergence meters) recording in a continuous fashion. This may also be routinely useful in identifying the stress level ahead of the face and the effectiveness of preconditioning blasts.

5.1.7 Conformance with contractual project outputs

5.1.7.1 Enabling output 1: Guidelines for the implementation of face-parallel preconditioning

After the BGM 17-24W project site was closed early in 1996, attention was focused on the establishment of the LGM 25-55W site. Unfortunately, delays in the preparation of the site resulted in the initiation of the preconditioning experiment being postponed until early 1998. Thus, the objective of continuing to monitor a remnant pillar preconditioning site could not be attained, due to external factors beyond the control of the preconditioning project team.

However, the research work carried out at the BGM 17-24W project site had already provided substantial evidence for the effectiveness of face-parallel preconditioning. Based on the study conducted at that site, guidelines for a practicable preconditioning technique were formulated and refined, with the drawback of being based on experience at only one site. These guidelines for the implementation of face-parallel preconditioning are attached to this report as Appendix 2. The difficulties which had been encountered in terms of the use of stemming with face-parallel preconditioning led to various alternative strategies being devised, as reported in section 4.3.3; these have not yet been verified in practice.

5.1.7.2 Enabling output 2: Guidelines for the implementation of face-perpendicular preconditioning

The monitoring of the application of preconditioning at the WDLS 87-49W project site continued until early 1997, with much valuable information being obtained, despite a period during which the detrimental effects of a change in mining geometry inhibited any analysis of the effects of preconditioning on the rock mass. During the periods when the preconditioning was being applied more consistently, the effects of the preconditioning were significant, particularly when contrasted with the conditions of panels which were not being preconditioned. Guidelines for the implementation of face-perpendicular preconditioning were formulated and then refined on the basis of an optimisation study, which was conducted during the last period of field work at the site. These guidelines are attached to this report as Appendix 3.

5.1.7.3 Enabling output 3: The feasibility of forming an implementation team

The applicability of preconditioning as an implementable production technique has been assessed and it has been found that it is possible for both preconditioning techniques to be incorporated into a production cycle effectively. However, face-perpendicular preconditioning is clearly the more amenable for use under the production constraints of a normal mining stope. For face-parallel preconditioning to be used effectively, a mining strategy must be carefully devised and strictly adhered to. Adequate control over face shapes and advance rates is essential and preparation for the drilling of the preconditioning holes must be made in advance, to avoid unnecessary disruption of the production cycle.

An education and training scheme has been formulated (see Appendix 5), based on experience gained at the research sites and during involvement with pilot implementation programmes at other sites in the industry. One of the most important aspects of an effective implementation programme is the education of the workforce prior to the introduction of preconditioning to a new site. The workers must be made aware not only of how to apply the preconditioning correctly (and of the need to do so), but of the direct benefits to them in their working environment.

All levels of the production staff on the mine, as well as the training and safety staff, should be involved in the education and training process. 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.

An effective implementation team should consist of at least two individuals, one of whom understands the preconditioning concepts, the other being someone who can communicate effectively with the workforce and who is familiar with the more practical aspects of preconditioning. The preconditioning project team has been involved in initiating implementation field trials on suitable mines, in order to develop and verify the education and training scheme.

5.2 Recommendations

Preconditioning has been effective in enabling safer mining in seismically hazardous areas, wherever it has been implemented correctly, under suitable conditions. Owing to a fundamental lack of understanding of the preconditioning concept, certain mines have tried to implement this technique under inappropriate conditions. In some places, the use of preconditioning has been discontinued, due to resistance from production personnel, which resulted entirely from the adverse effects of incorrect application. Therefore, in order to assure the successful implementation of preconditioning in the mining industry, the following issues must be addressed :-

- There is a need to establish implementation teams in the mining industry. The specialised Miningtek preconditioning team can assist with the initiation of the implementation process on various mines. Since the mines' training staff should actively be involved during the implementation process, the mines can continue building additional teams from their own resources, with limited further involvement of Miningtek's preconditioning team.

- The proposed implementation process has been formulated by the project team on the basis of a number of years of experience. The preconditioning guidelines given in this report should be adequate for the purpose of initiating preconditioning at a new site. Each mine should adapt and modify the details of the application of preconditioning according to their own needs, once the process of preconditioning has been well-established at a given site.

- The inclusion of preconditioning as part of the mine's Code of Practice 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 mechanics personnel.

- Finally, it is recommended that a separate '*Preconditioning Guide Book*' be compiled, as an easily accessible reference for use by rock mechanics practitioners and production personnel.

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Supplementary reading

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Appendix 1

Convergence-ride measurements at WDLS 87-49W

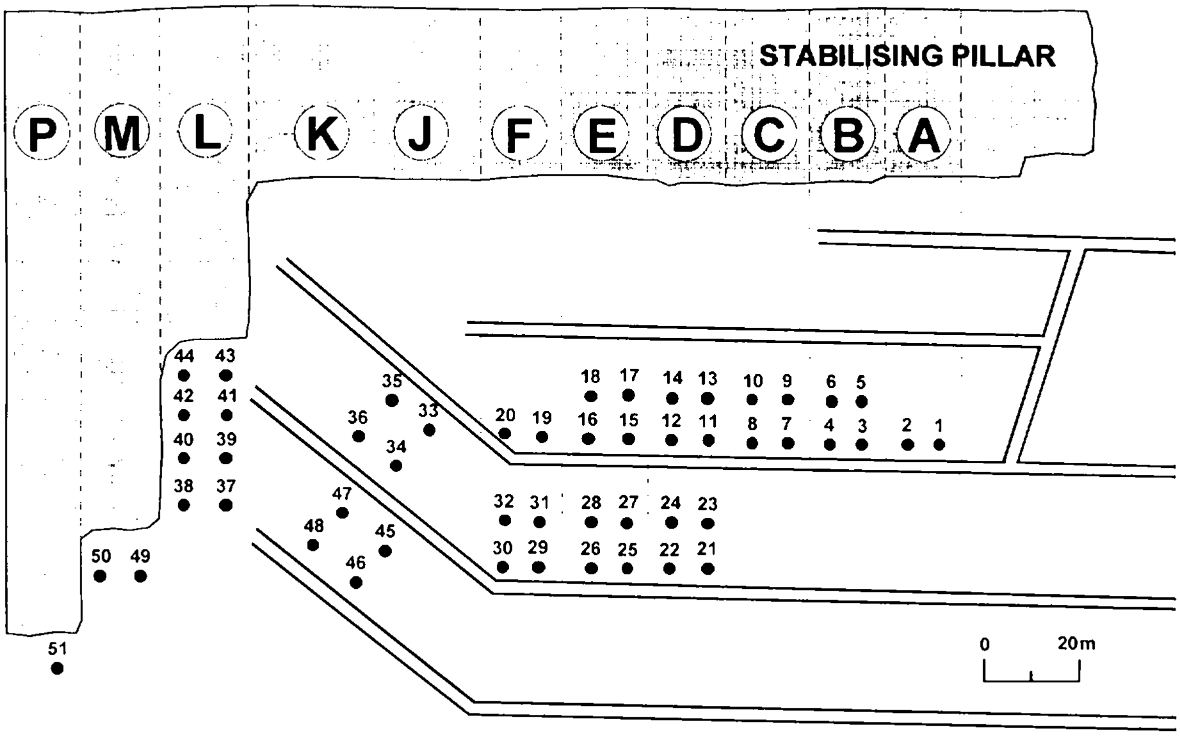

Figure 1 : Convergence-ride stations at WDLS preconditioning site.

NUMBER (FIGURE 1)	STATION NAME	NUMBER (FIGURE 1)	STATION NAME
1	4WE00A	27	3WE01E
2	4WW00A	28	3WW01E
3	4WE00B	29	3WE00F
4	4WW00B	30	3WW00F
5	4WE02B	31	3WE01F
6	4WW02B	32	3WW01F
7	4WE00C	33	3WE00J
8	4WW00C	34	3WW00J
9	4WE02C	35	3WE01J
10	4WW02C	36	3WW01J
11	4WE00D	37	3WE00L
12	4WW00D	38	3WW00L
13	4WE01D	39	3WE01L
14	4WW01D	40	3WW01L
15	4WE00E	41	3WE02L
16	4WW00E	42	3WW02L
17	4WE01E	43	3WE03L
18	4WW01E	44	3WW03L
19	4WE00F	45	2WE00K
20	4WW00F	46	2WW00K
21	3WE00D	47	2WE01K
22	3WW00D	48	2WW01K
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24	3WW01D	50	1WW00M
25	3WE00E	51	1WE00P
26	3WW00E		

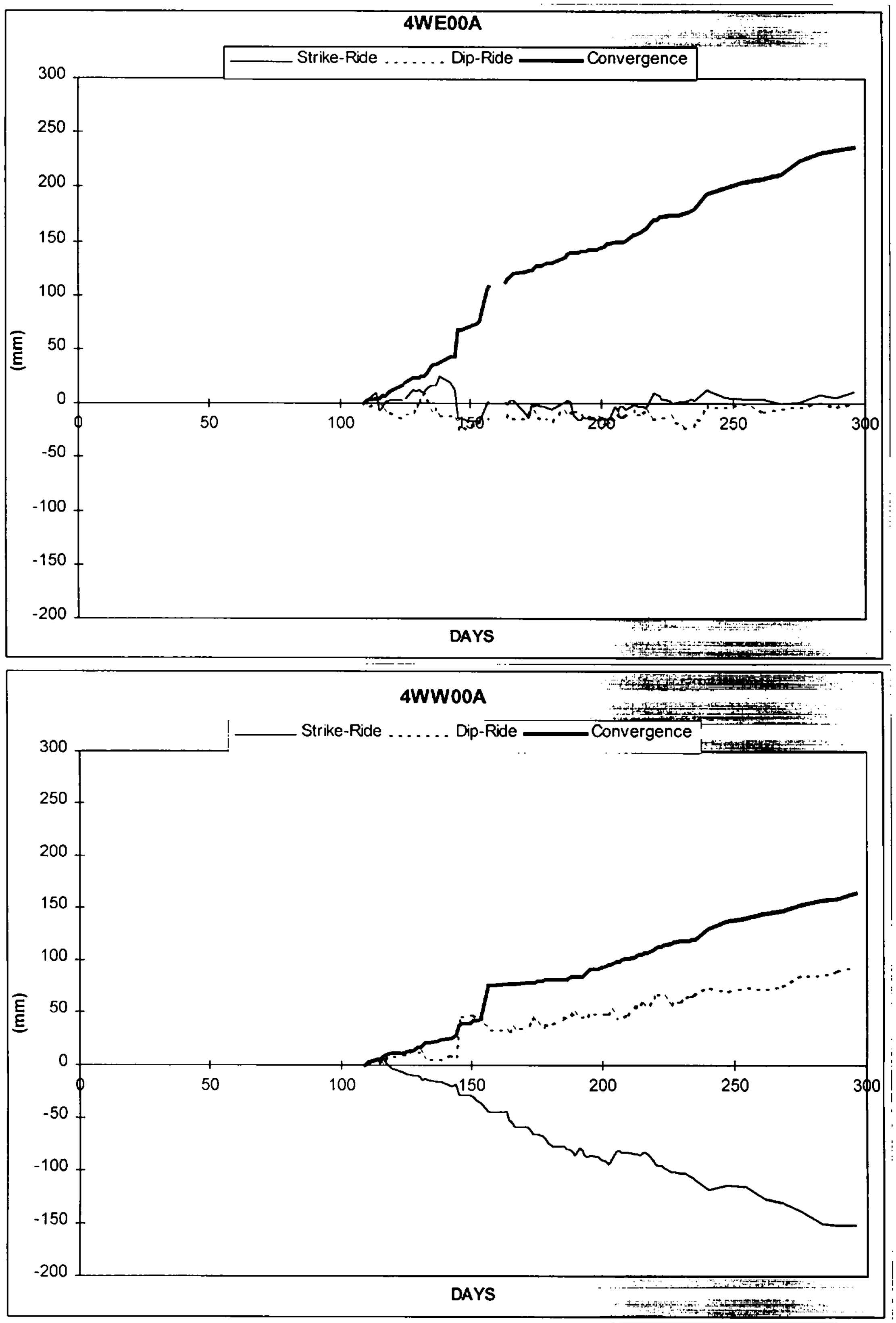


Figure 2 : Convergence-ride measurements at stations 1 & 2 (Refer to Figure 1).

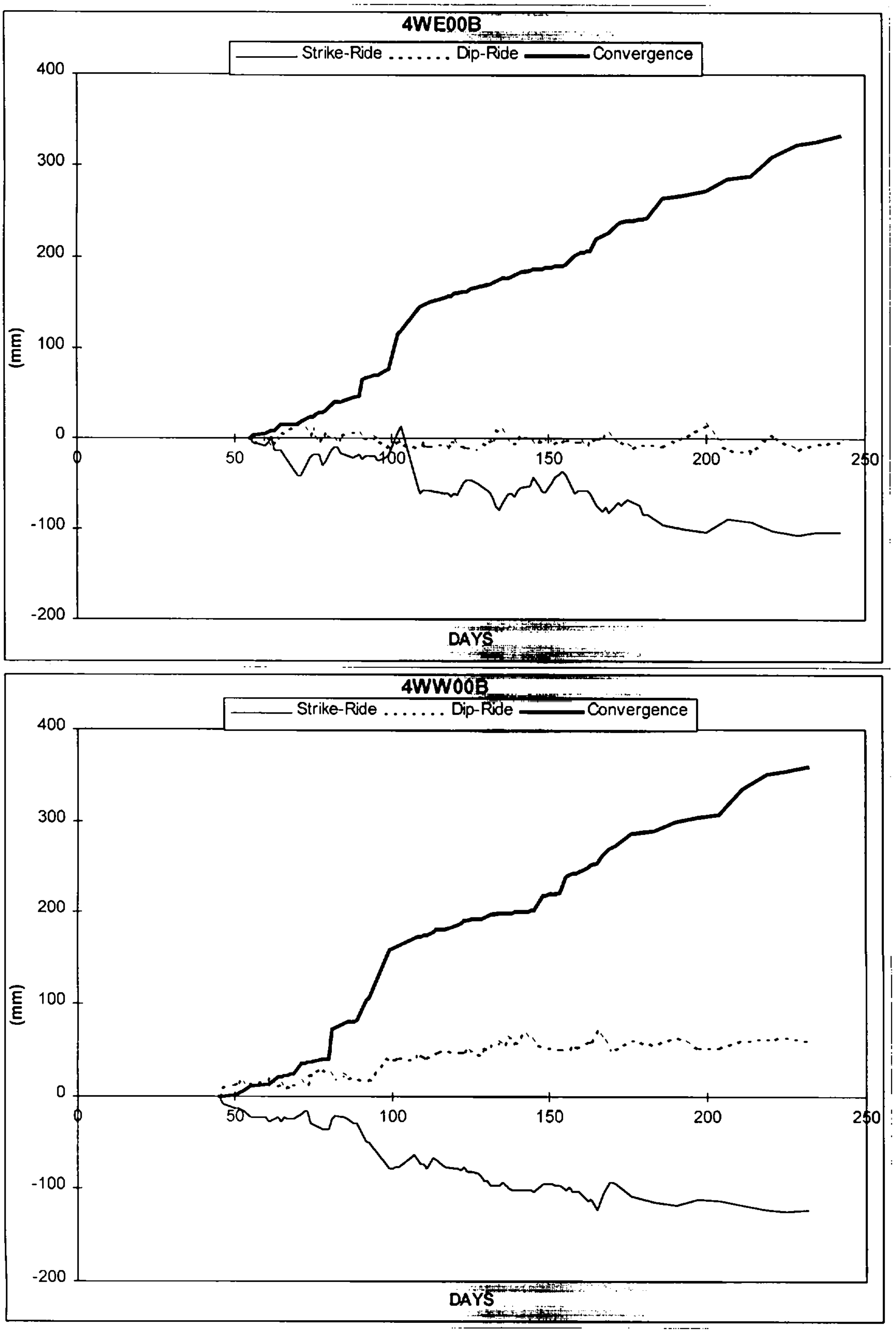
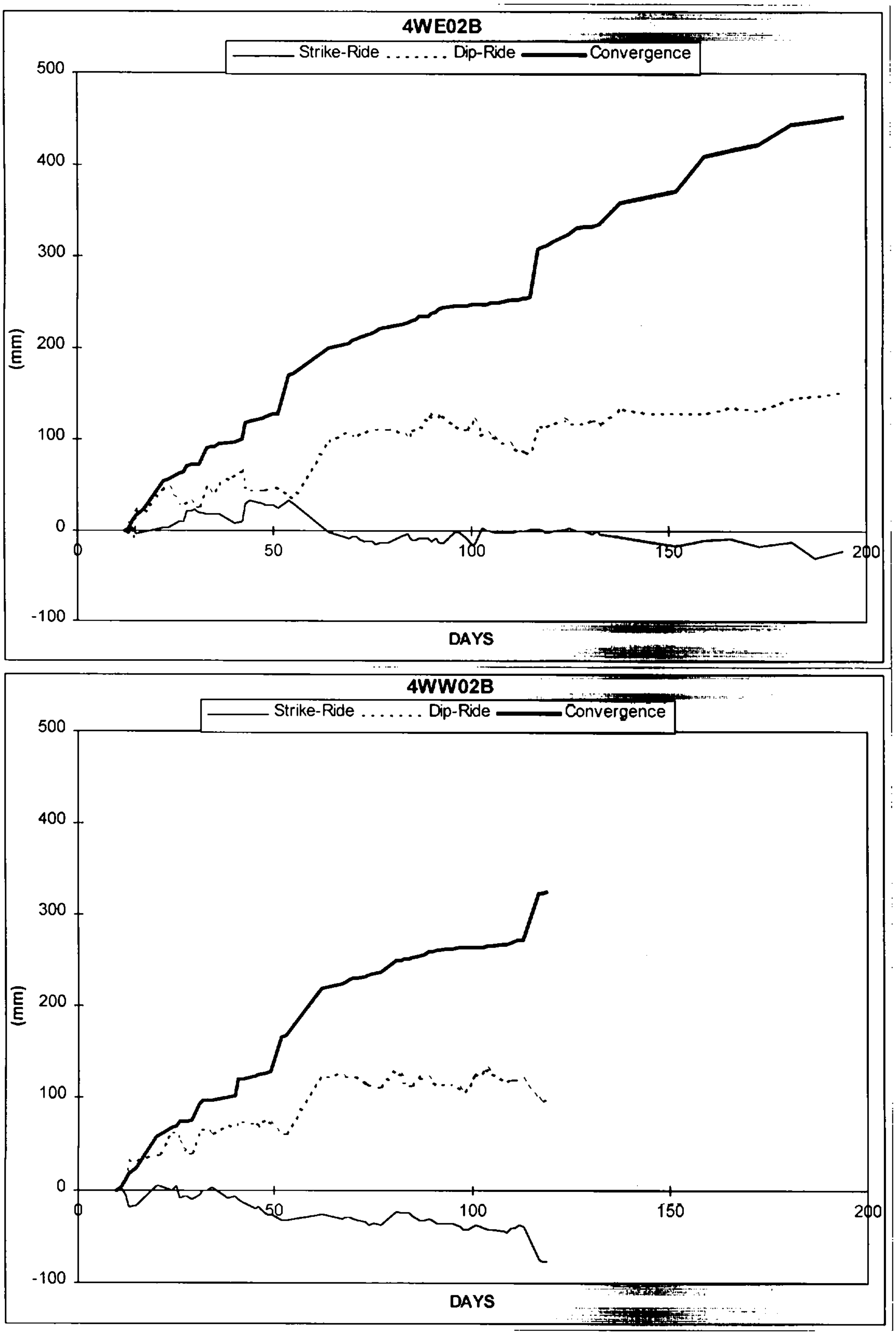


Figure 3 : Convergence-ride measurements at stations 3 & 4 (Refer to Figure 1).



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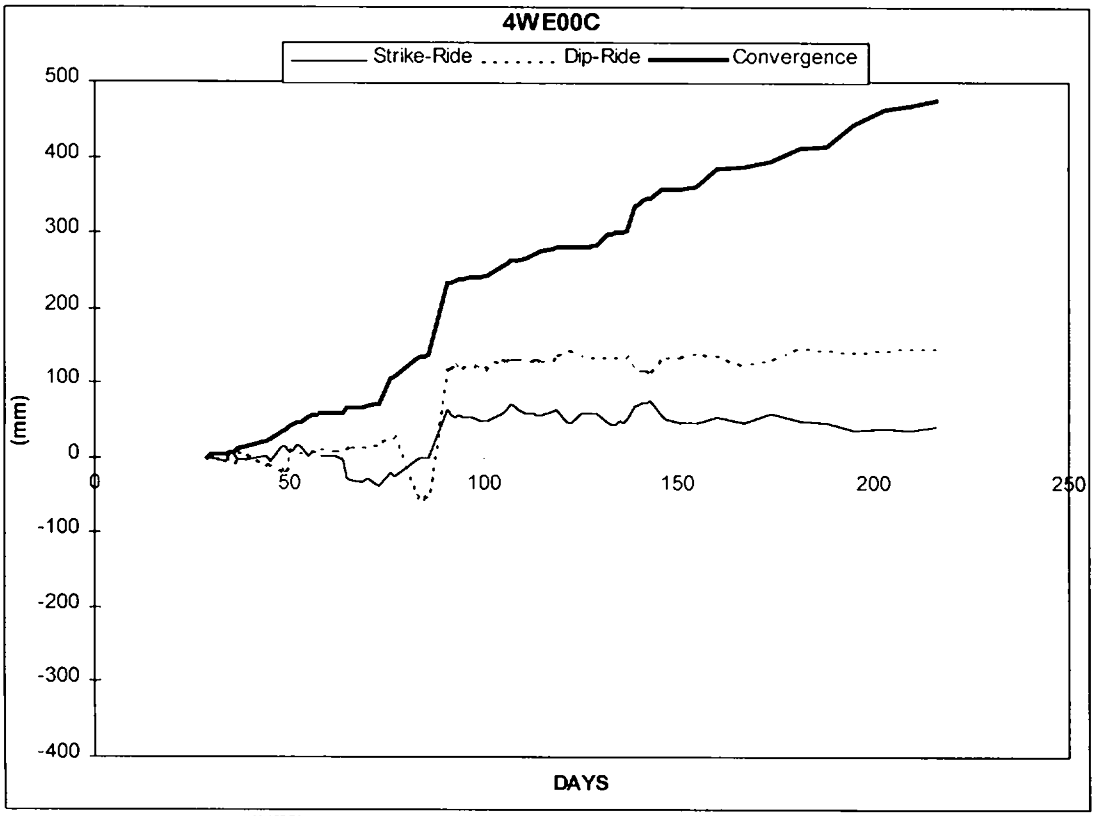


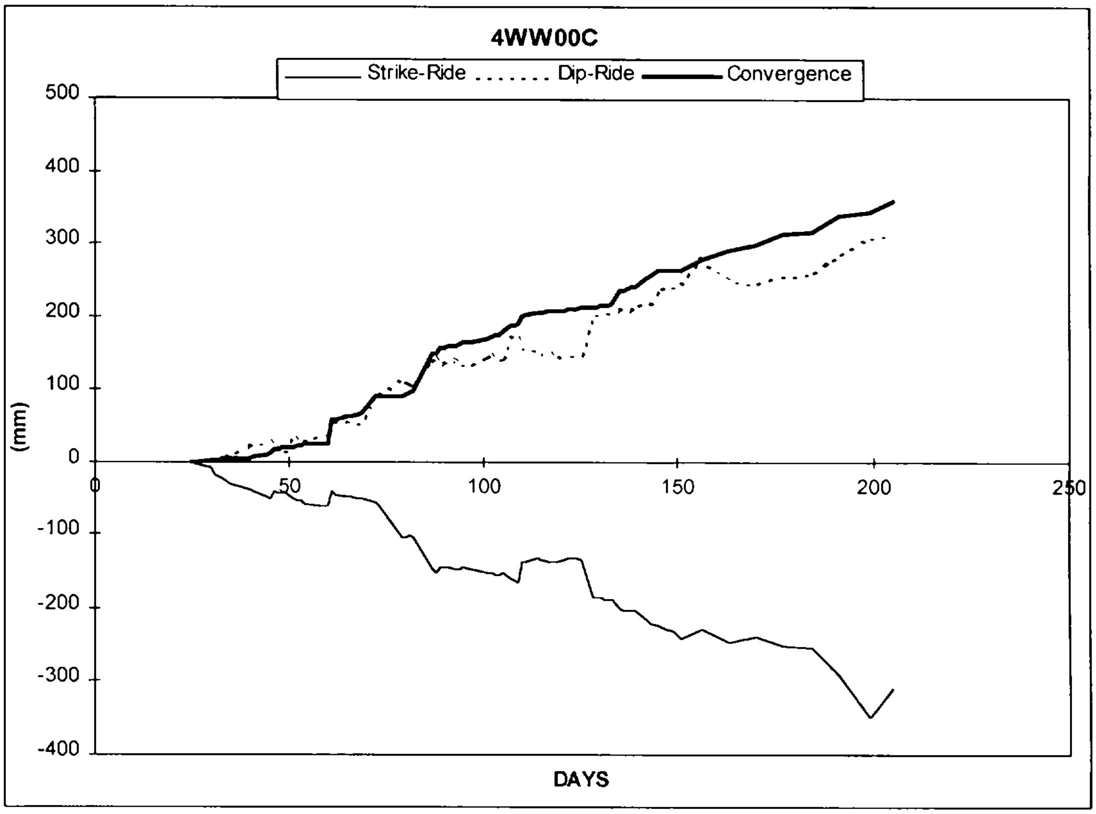
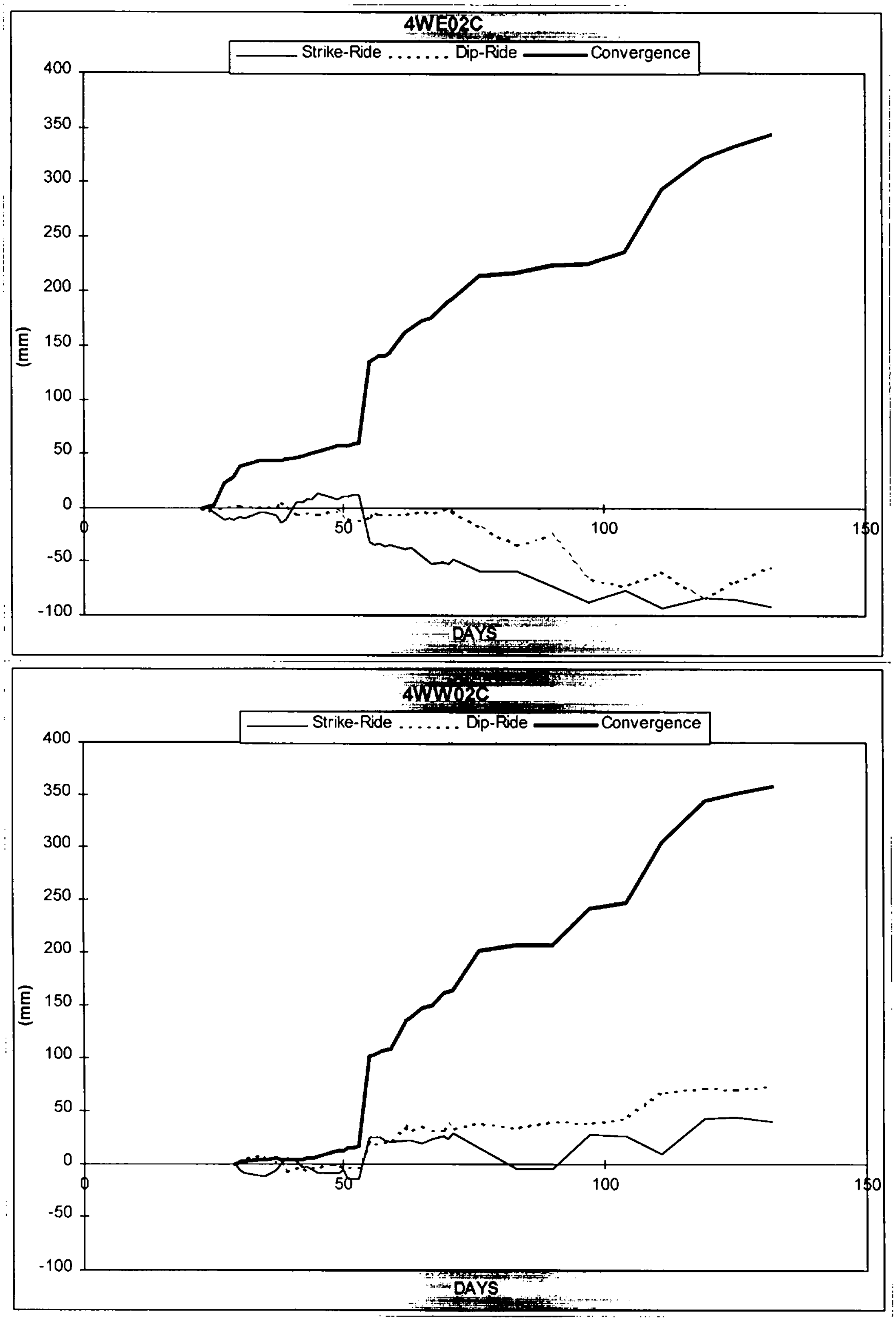


Figure 5 : Convergence-ride measurements at stations 7 & 8 (Refer to Figure 1).



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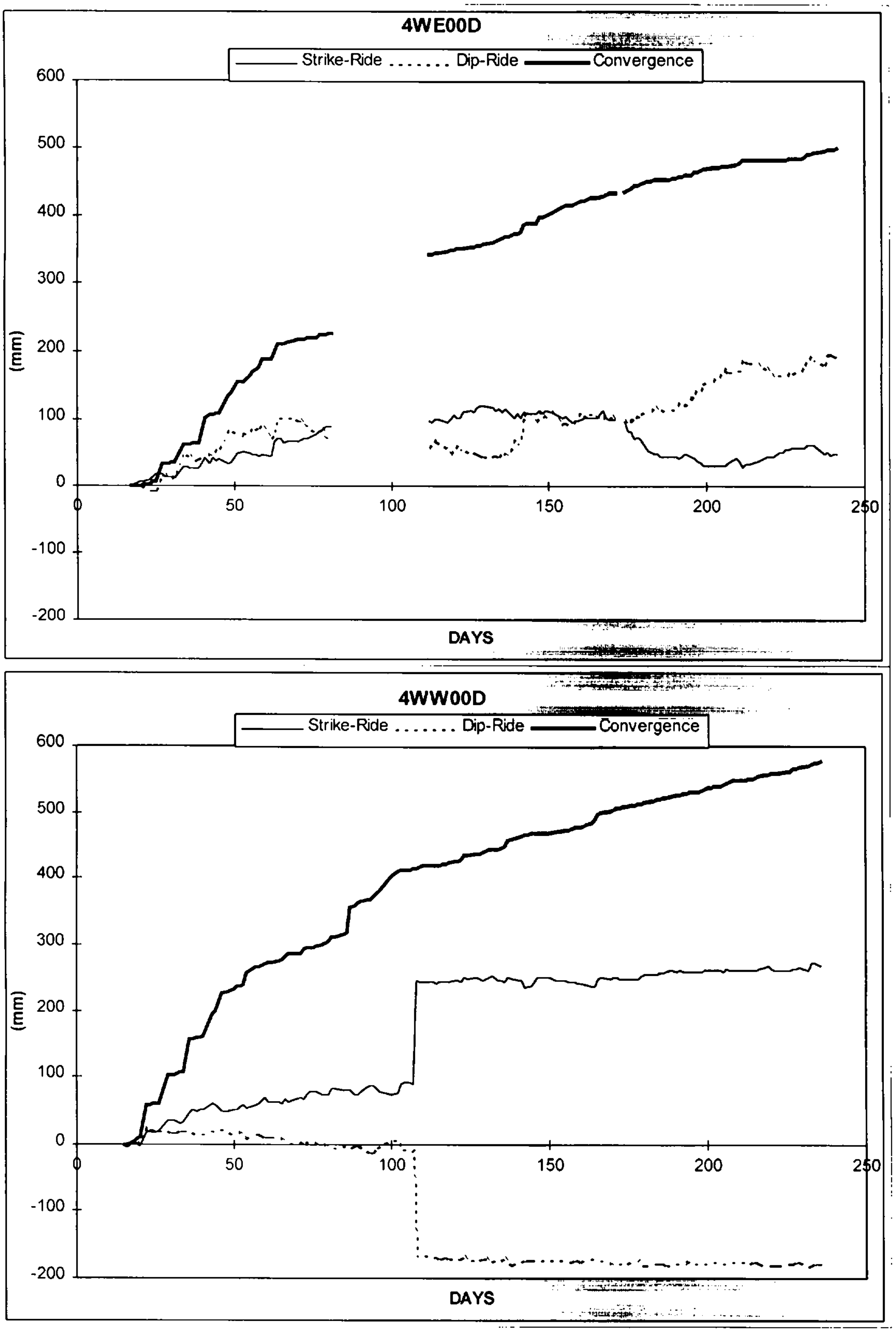


Figure 7 : Convergence-ride measurements at stations 11 & 12 (Refer to Figure 1).

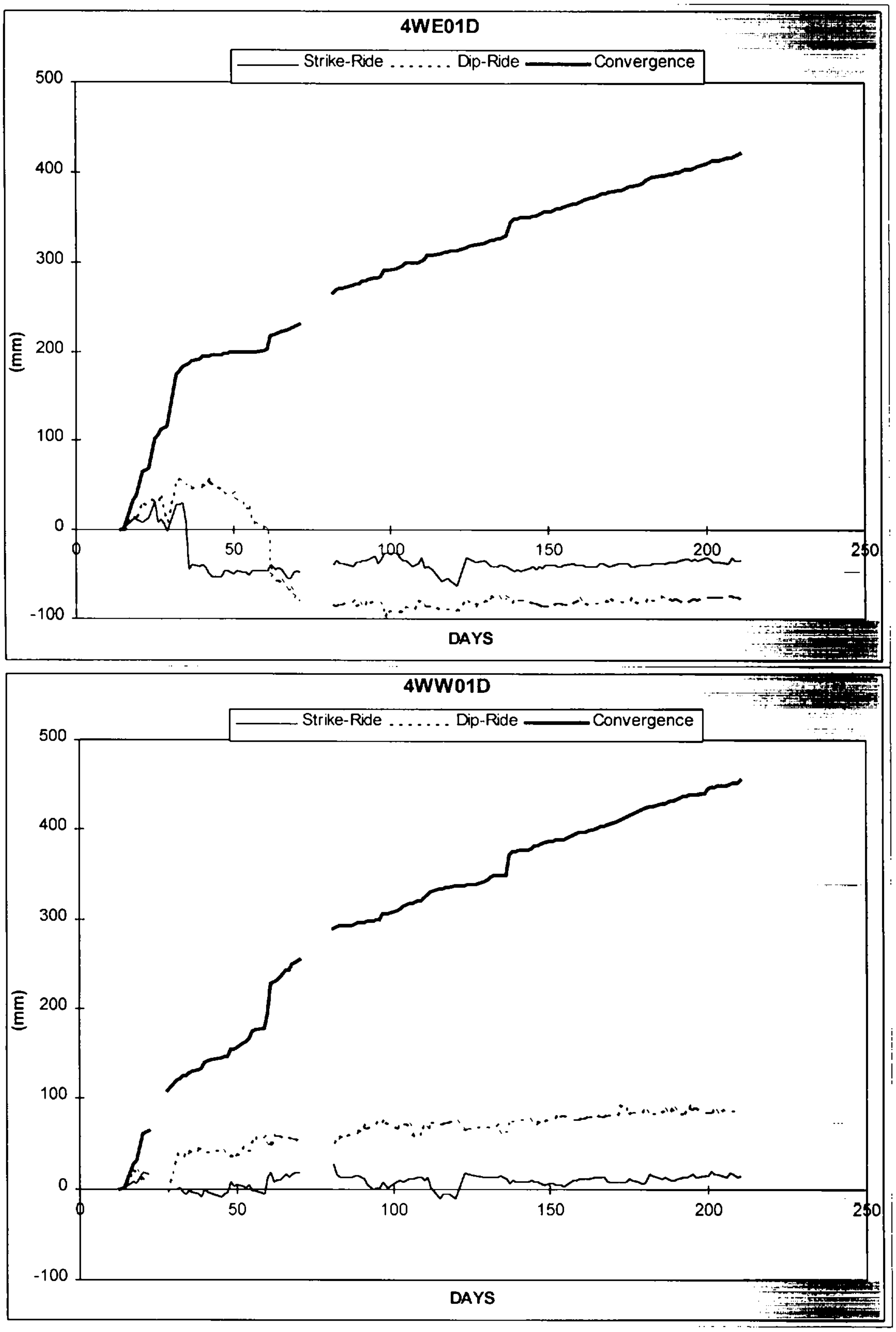


Figure 8 : Convergence-ride measurements at stations 13 & 14 (Refer to Figure 1).

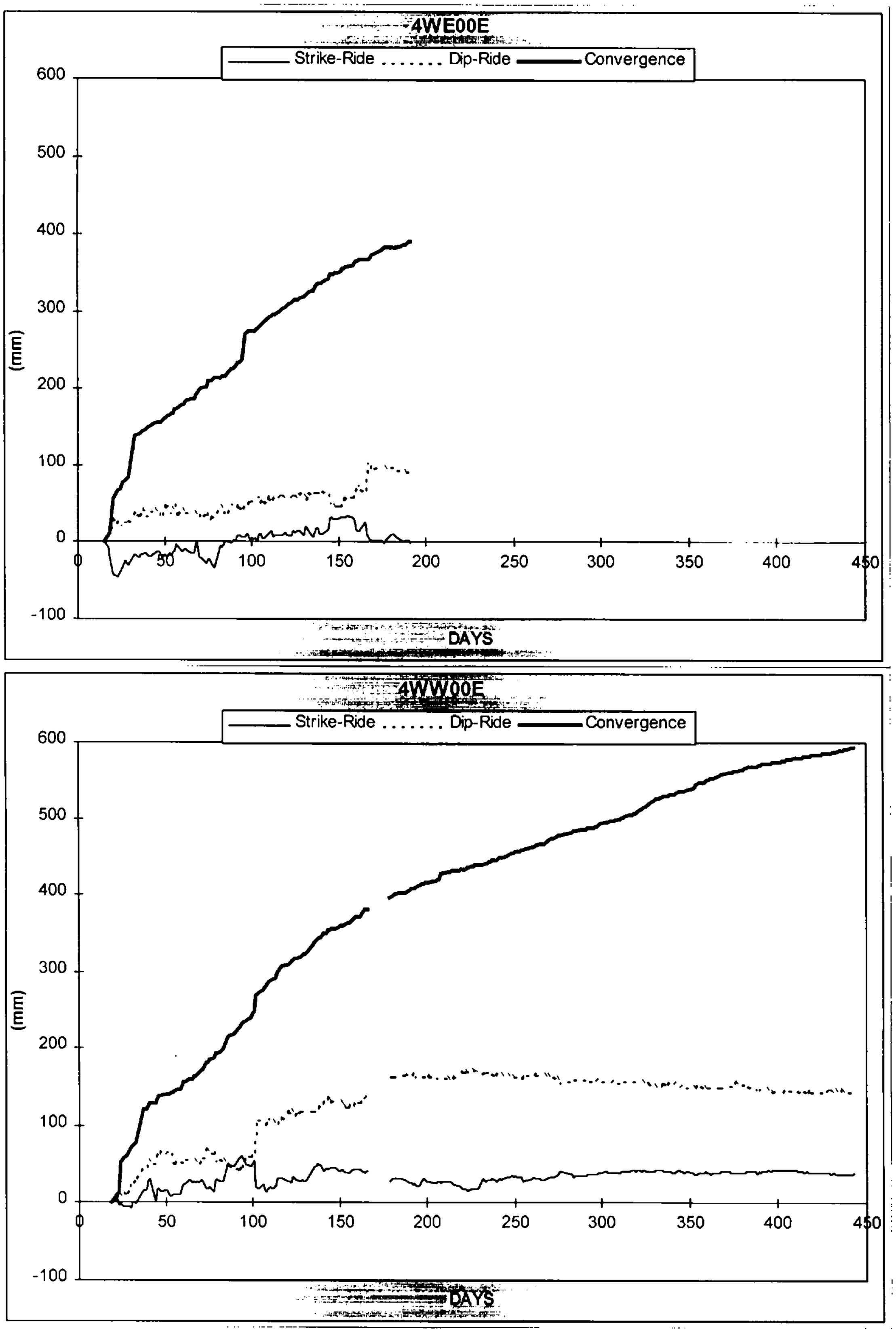
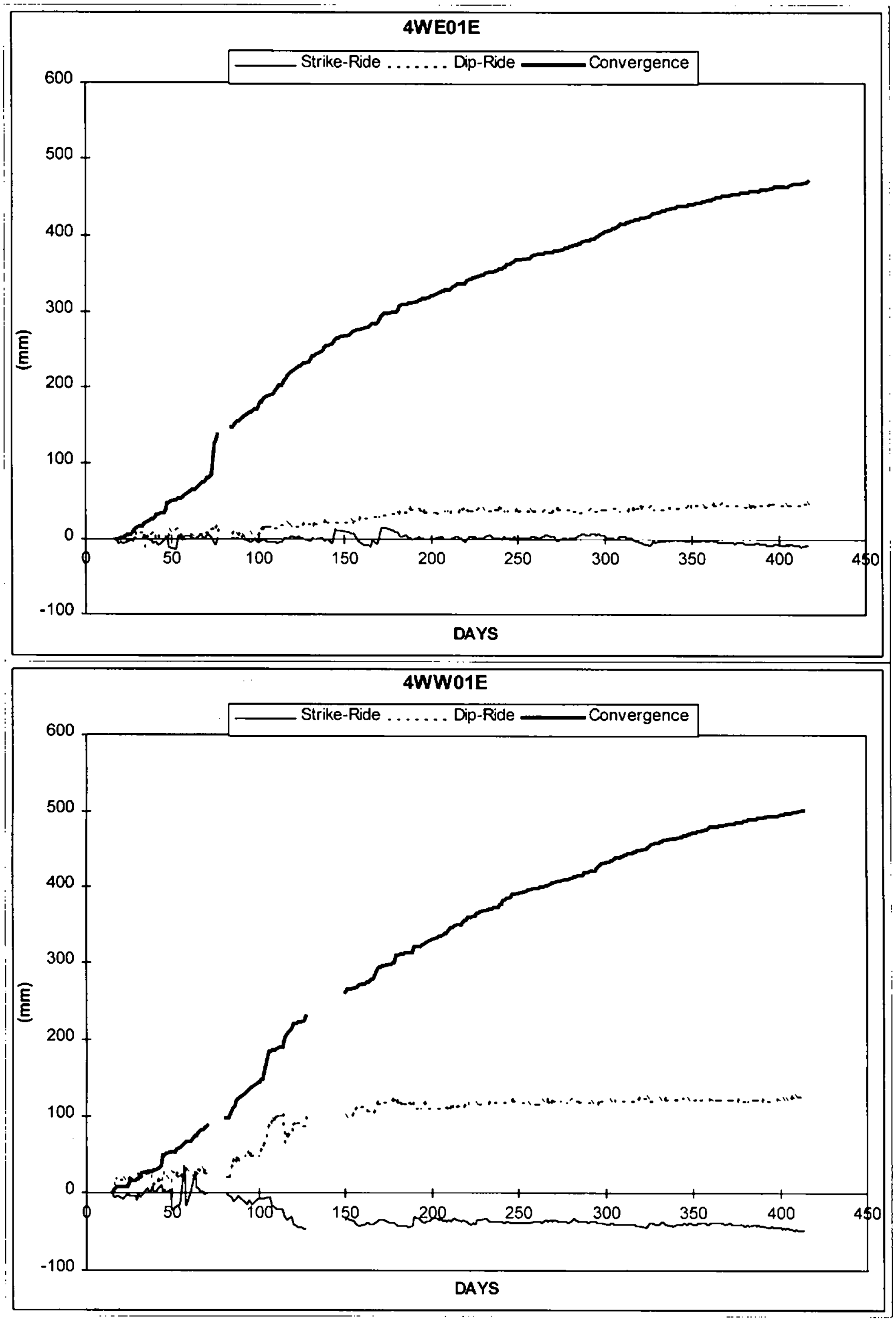


Figure 9 : Convergence-ride measurements at stations 15 & 16 (Refer to Figure 1).



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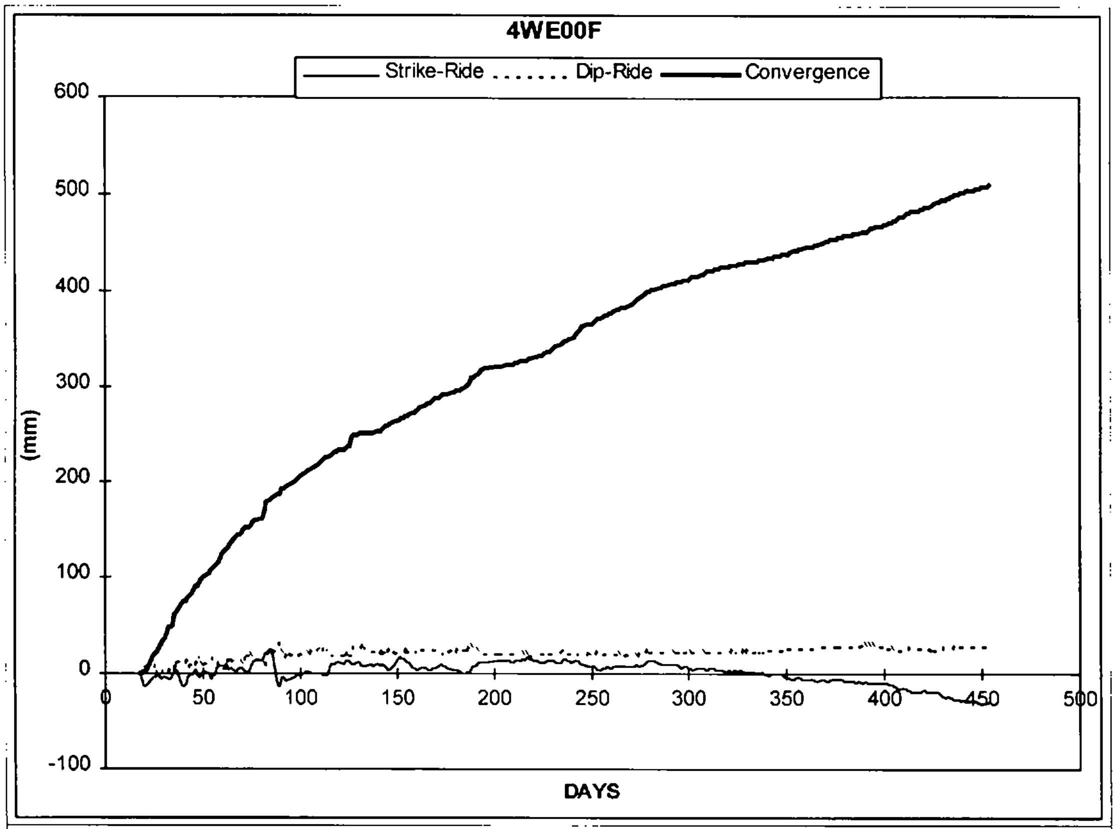


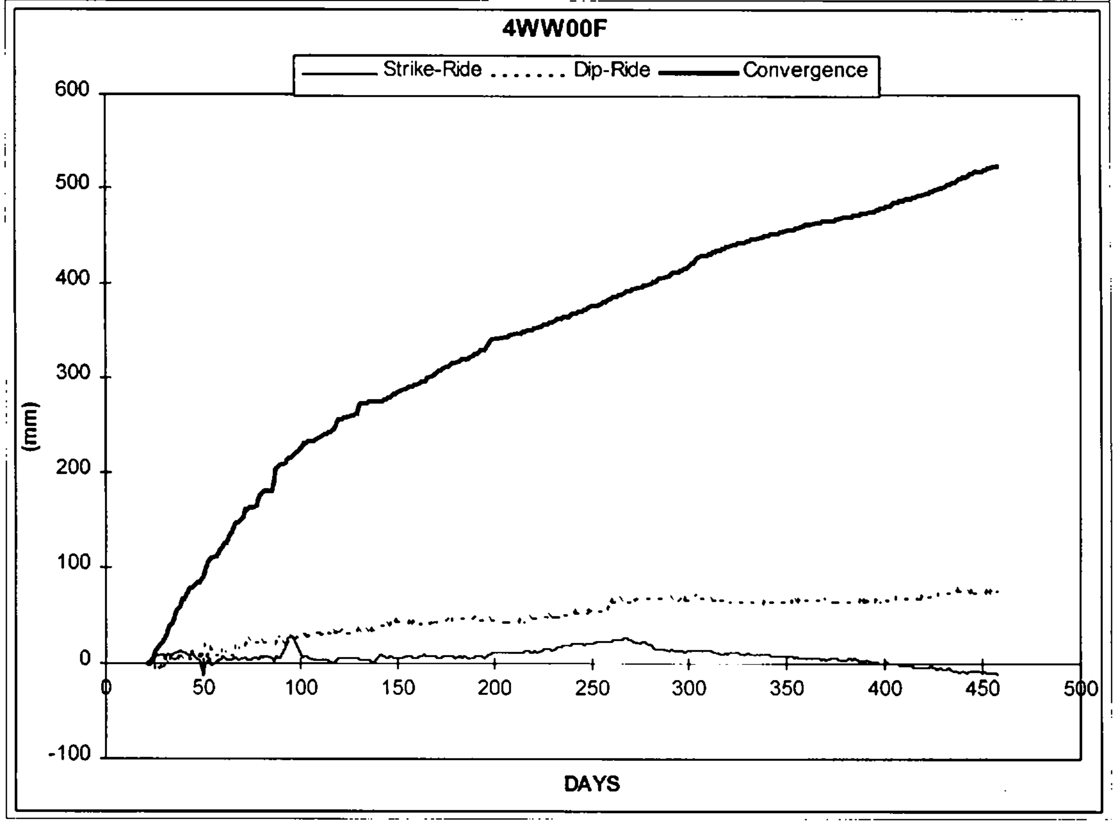
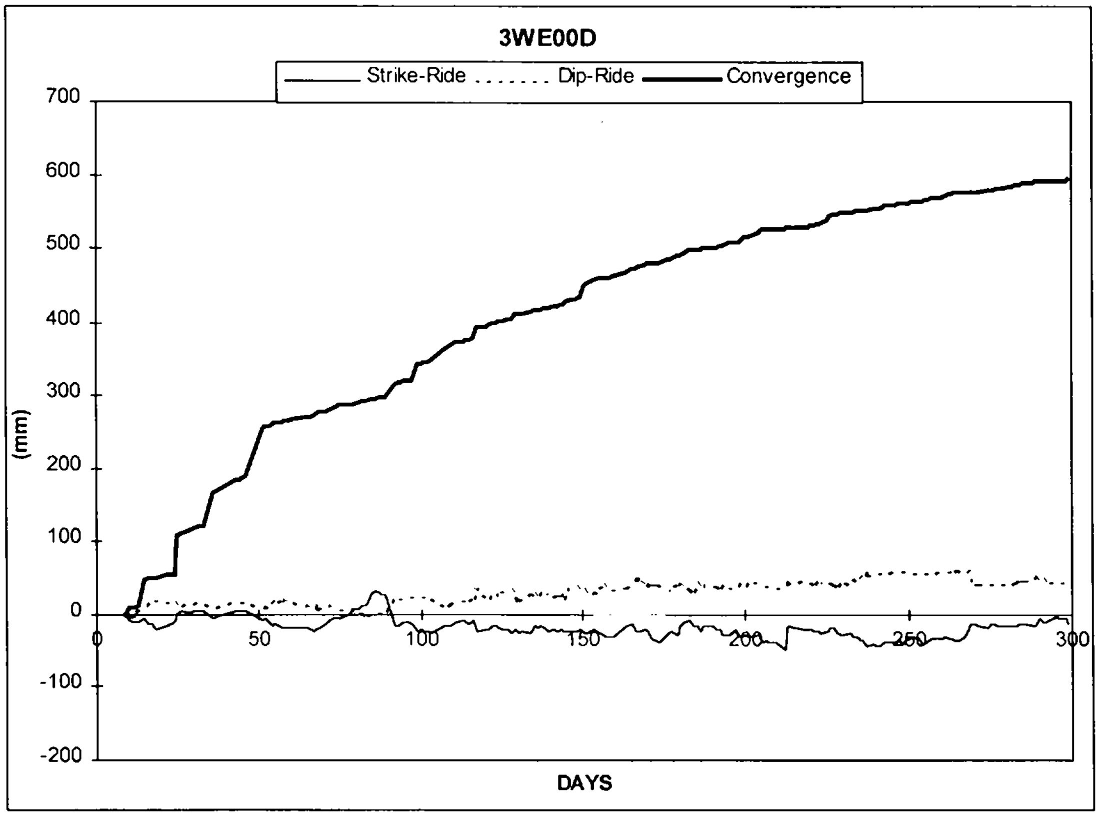


Figure 11 : Convergence-ride measurements at stations 19 & 20 (Refer to Figure 1).



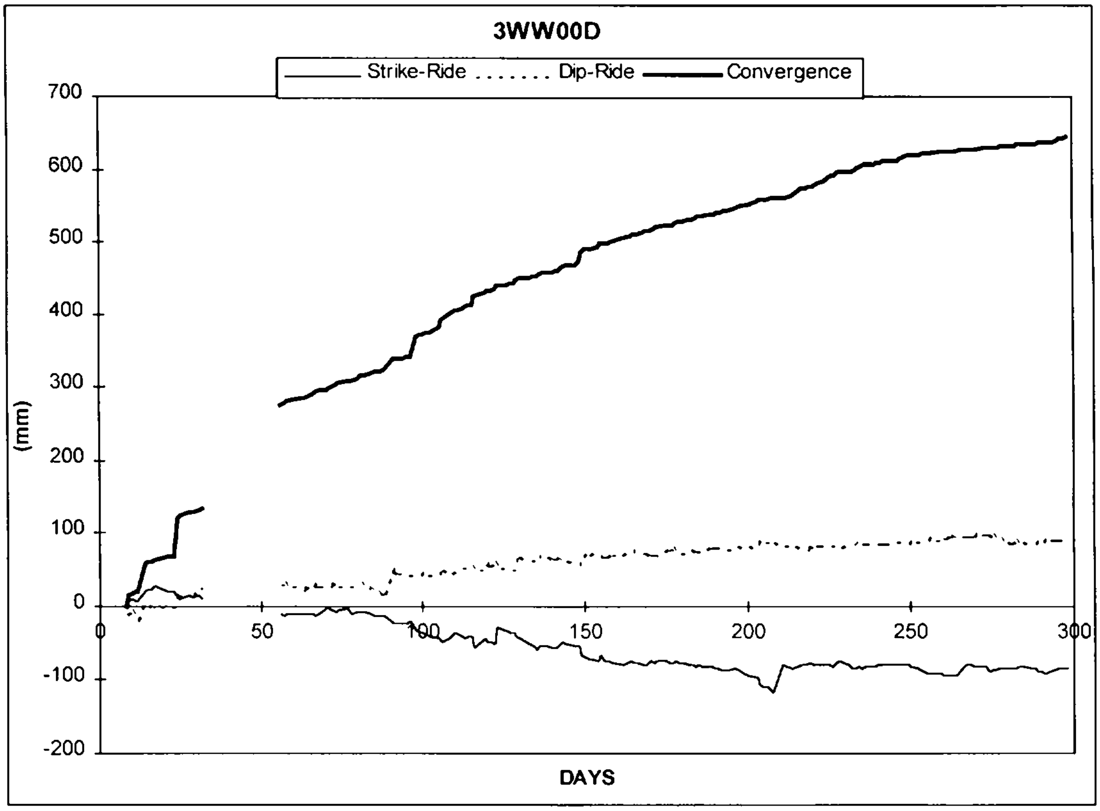


Figure 12 : Convergence-ride measurements at stations 21 & 22 (Refer to Figure 1).

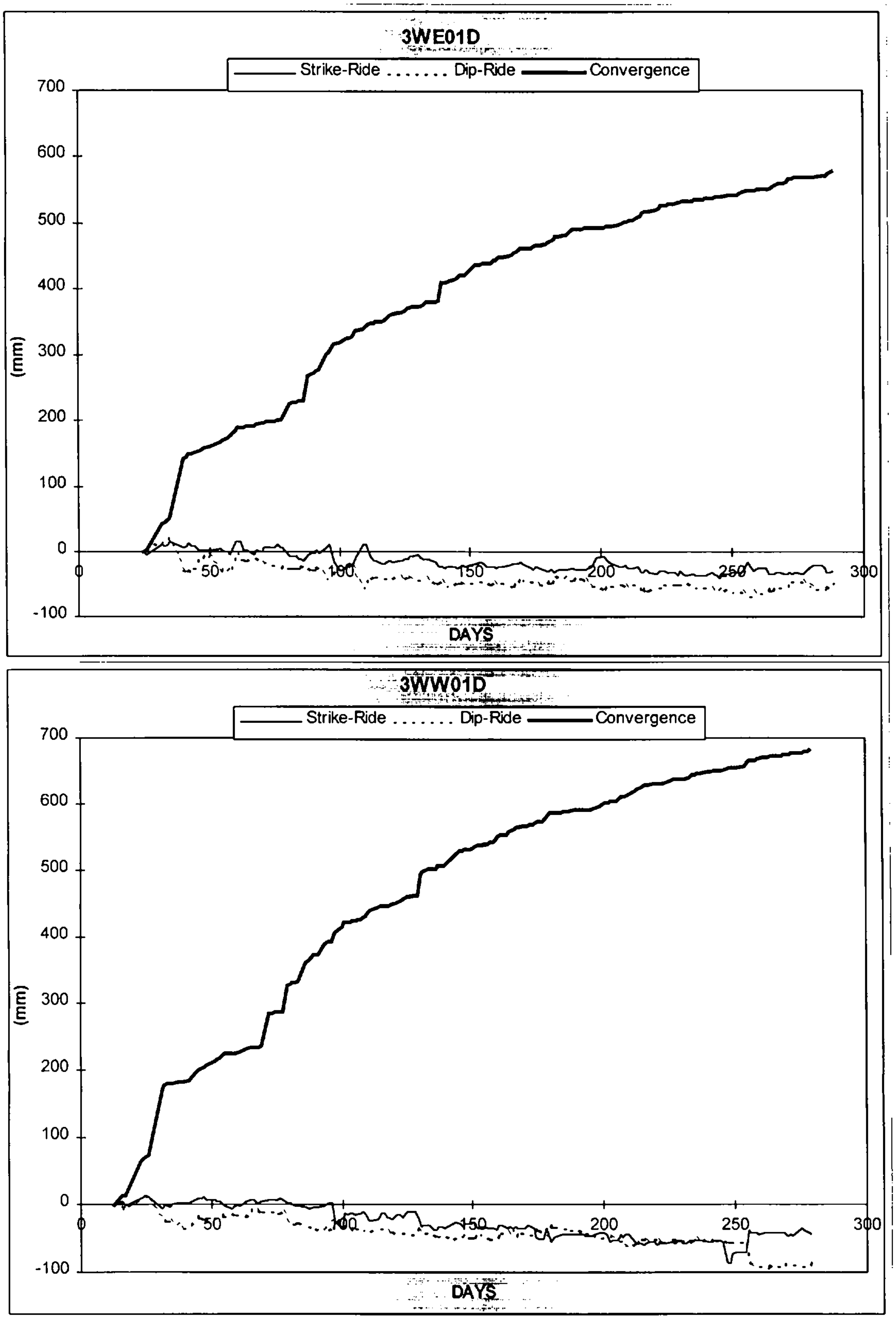
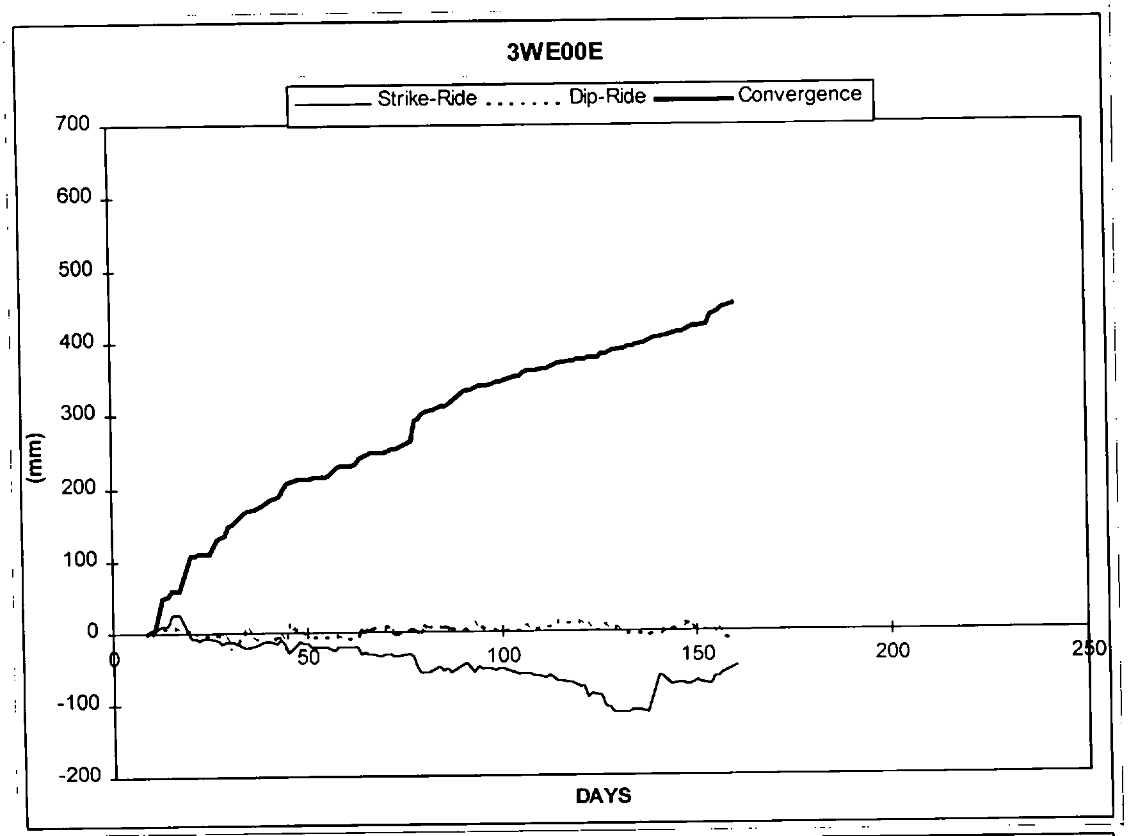


Figure 13 : Convergence-ride measurements at stations 23 & 24 (Refer to Figure 1).



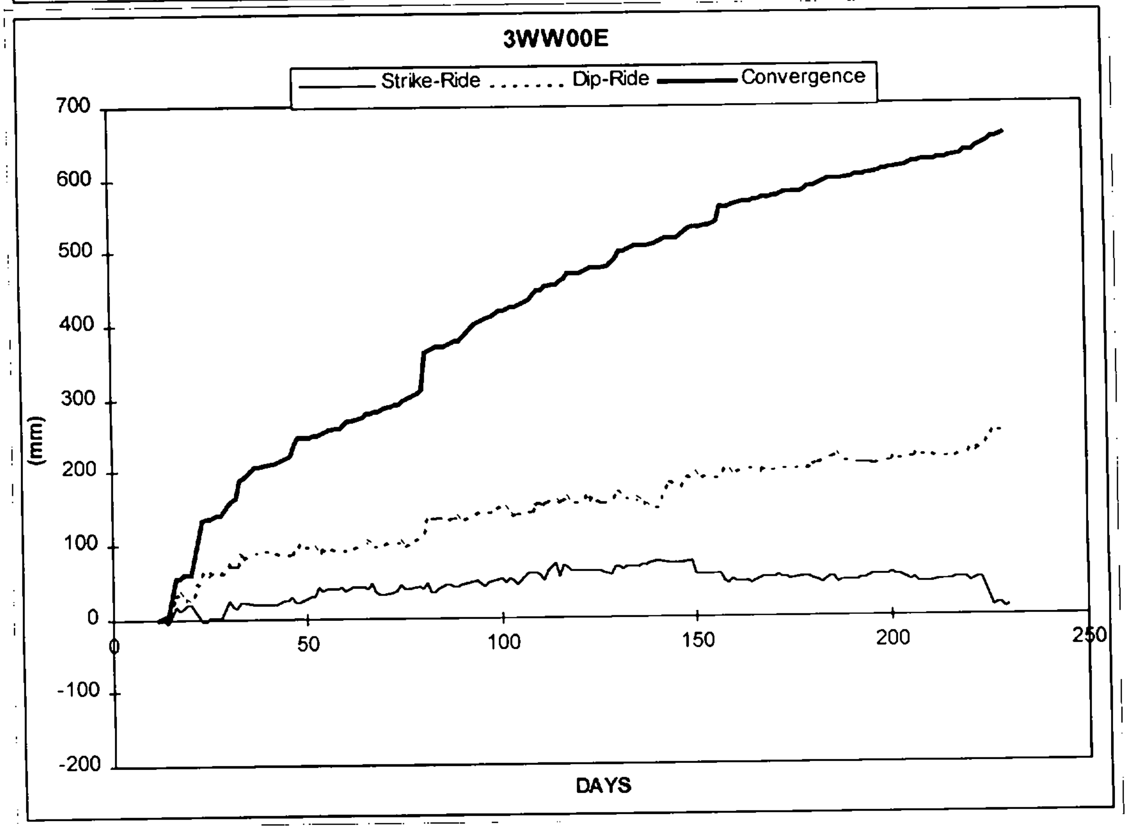
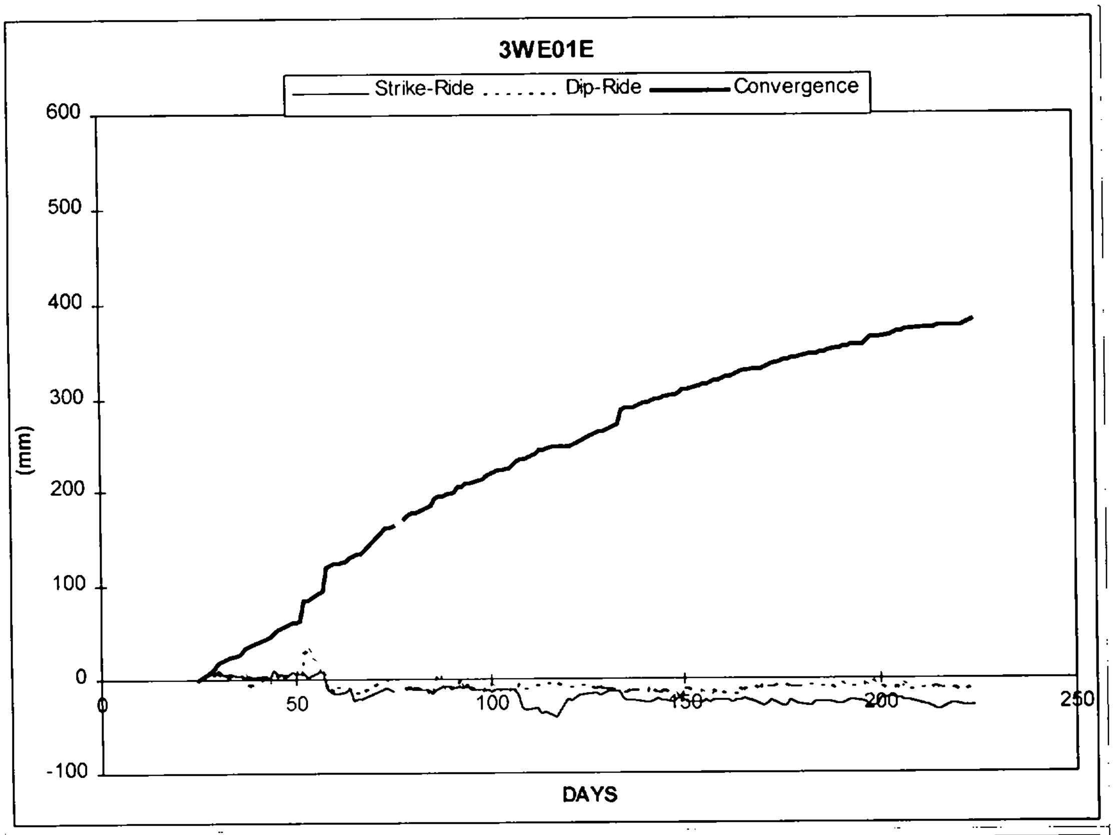


Figure 14 : Convergence-ride measurements at stations 25 & 26 (Refer to Figure 1).



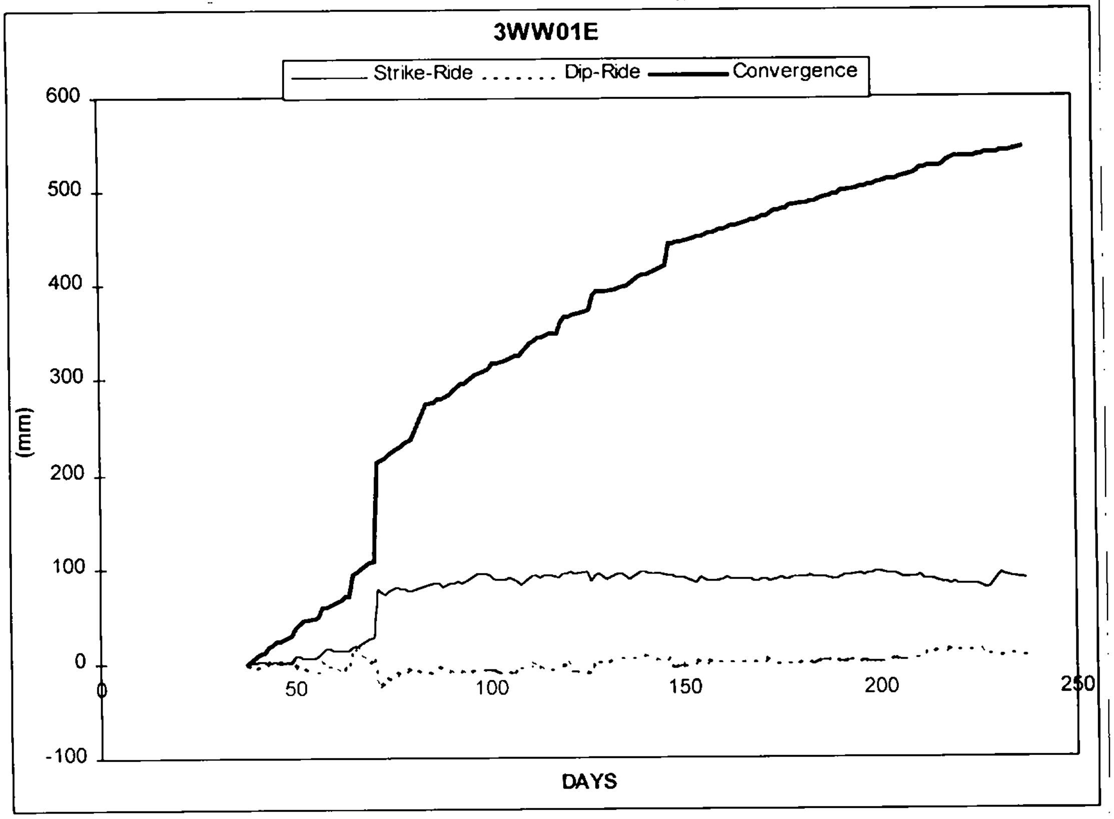


Figure 15 : Convergence-ride measurements at stations 27 & 28 (Refer to Figure 1).

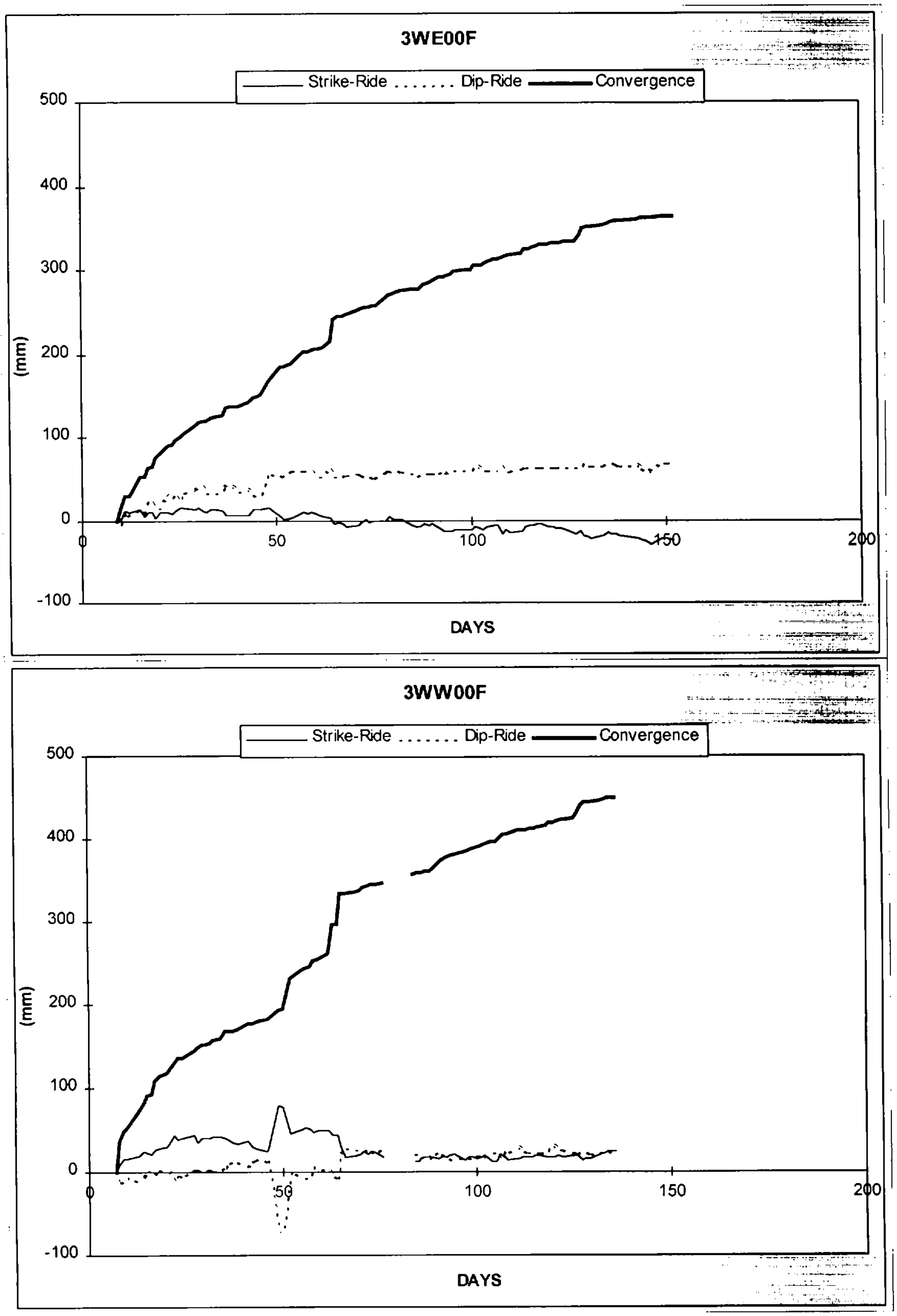
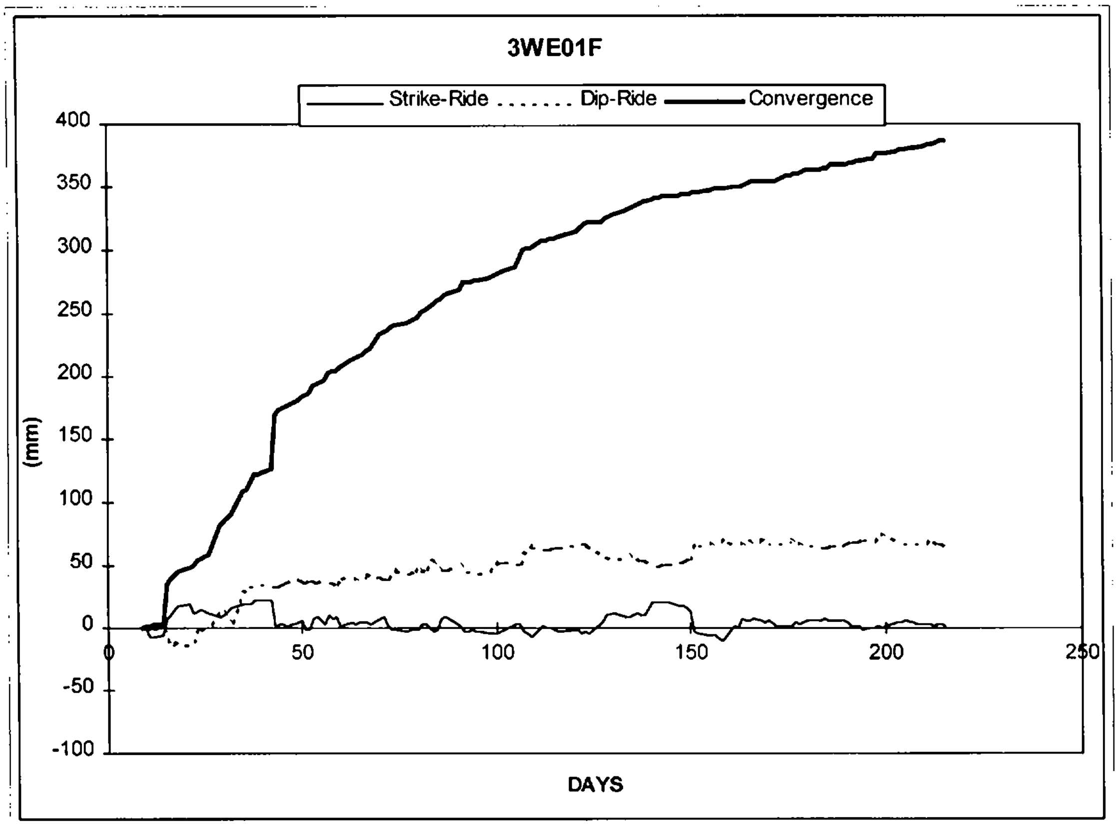


Figure 16 : Convergence-ride measurements at stations 29 & 30 (Refer to Figure 1).



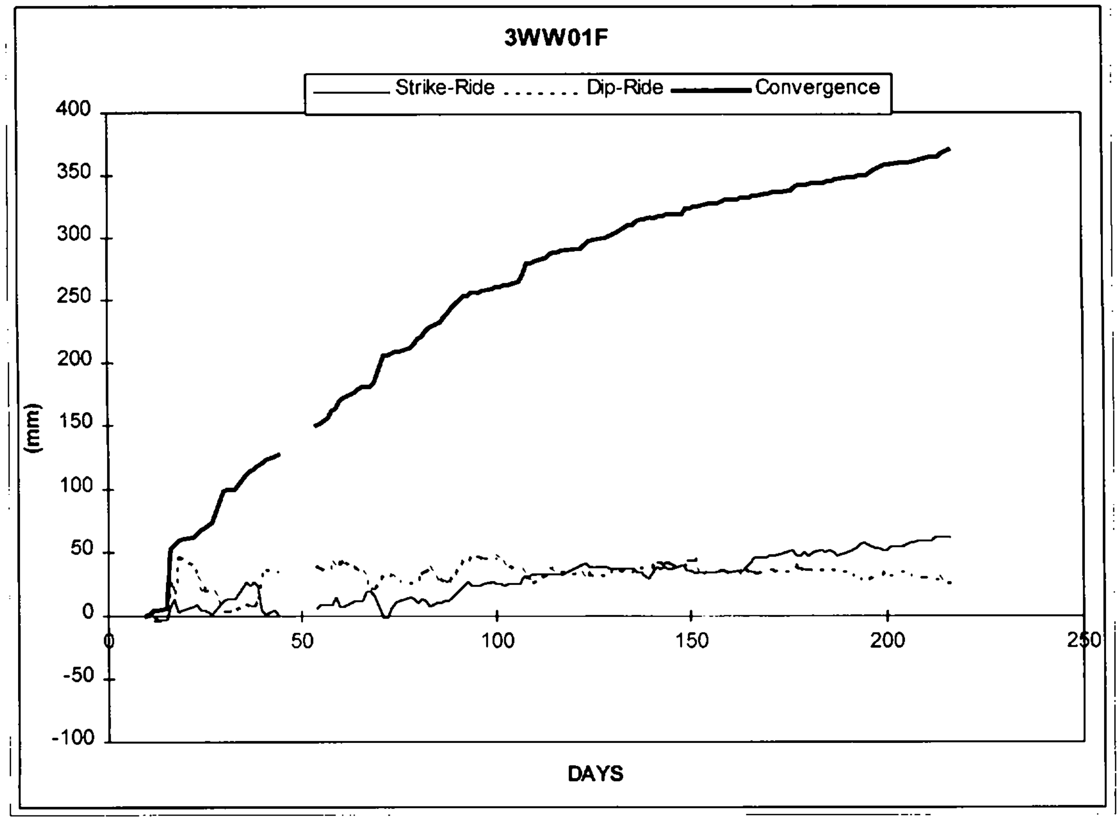
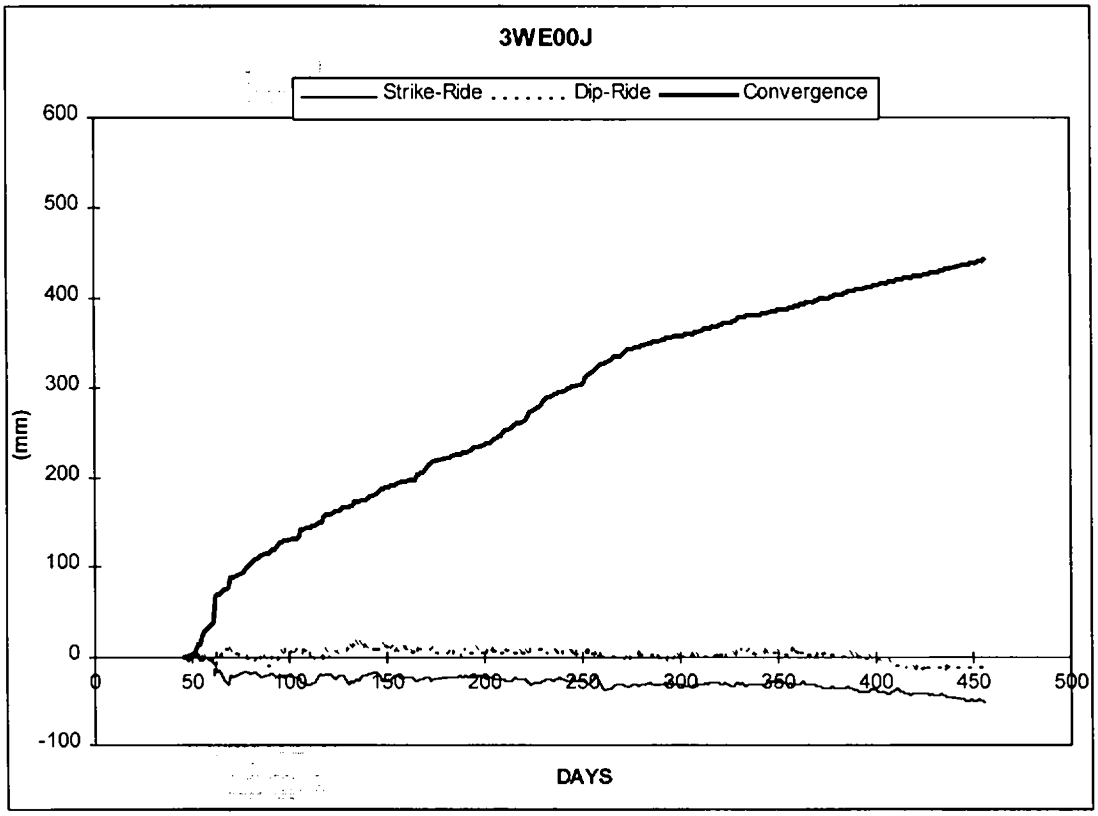


Figure 17 : Convergence-ride measurements at stations 31 & 32 (Refer to Figure 1).



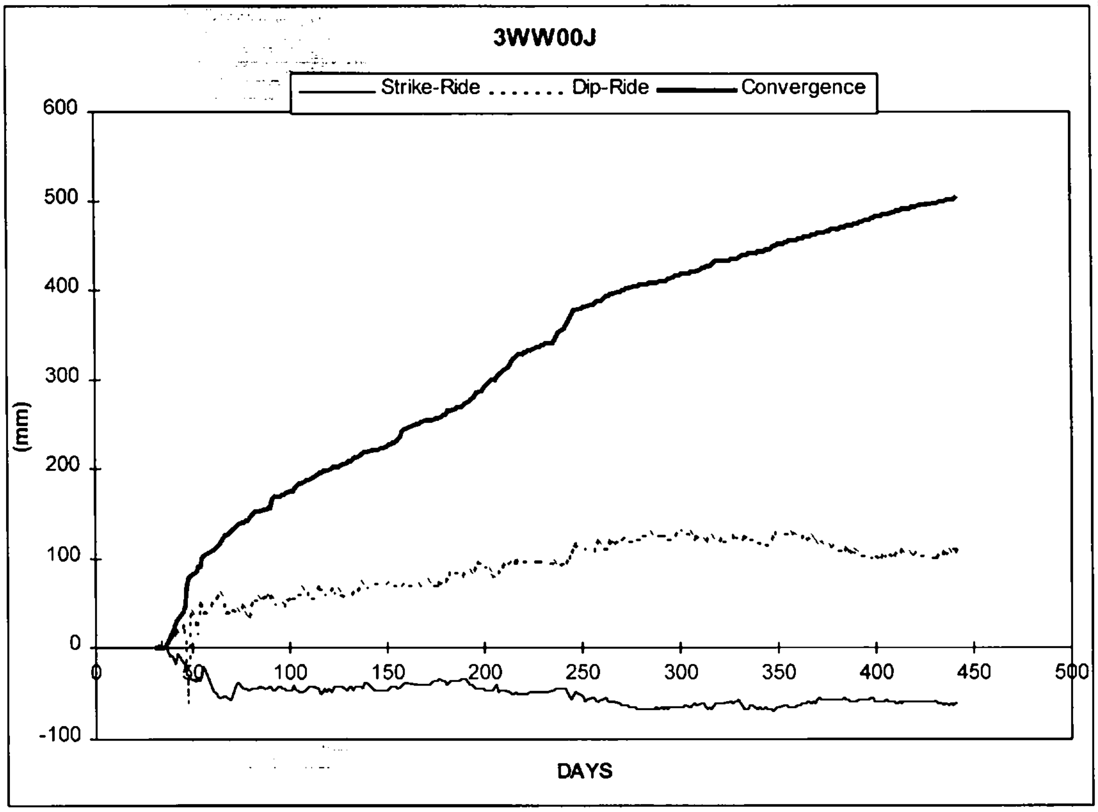


Figure 18 : Convergence-ride measurements at stations 33 & 34 (Refer to Figure 1).

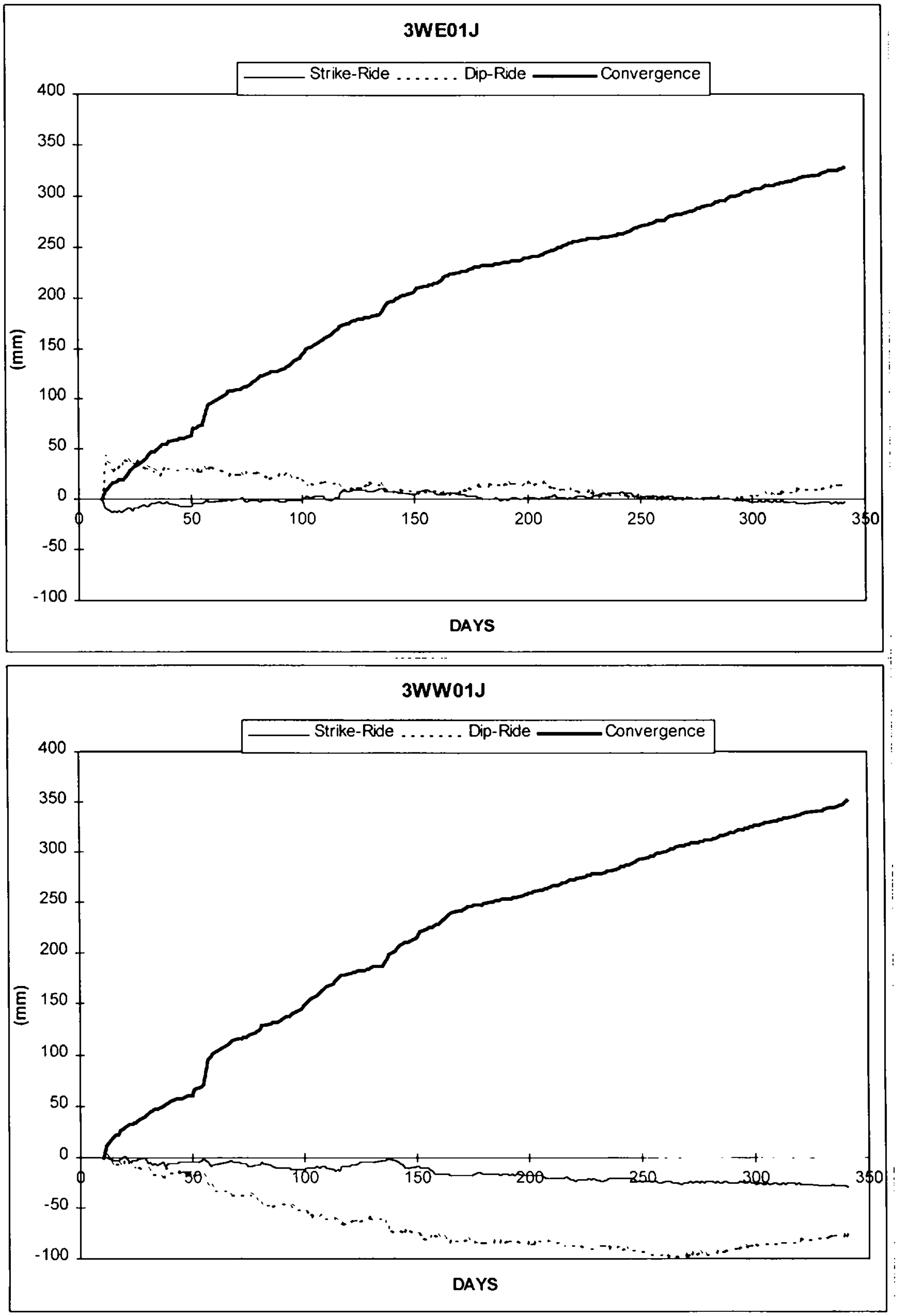
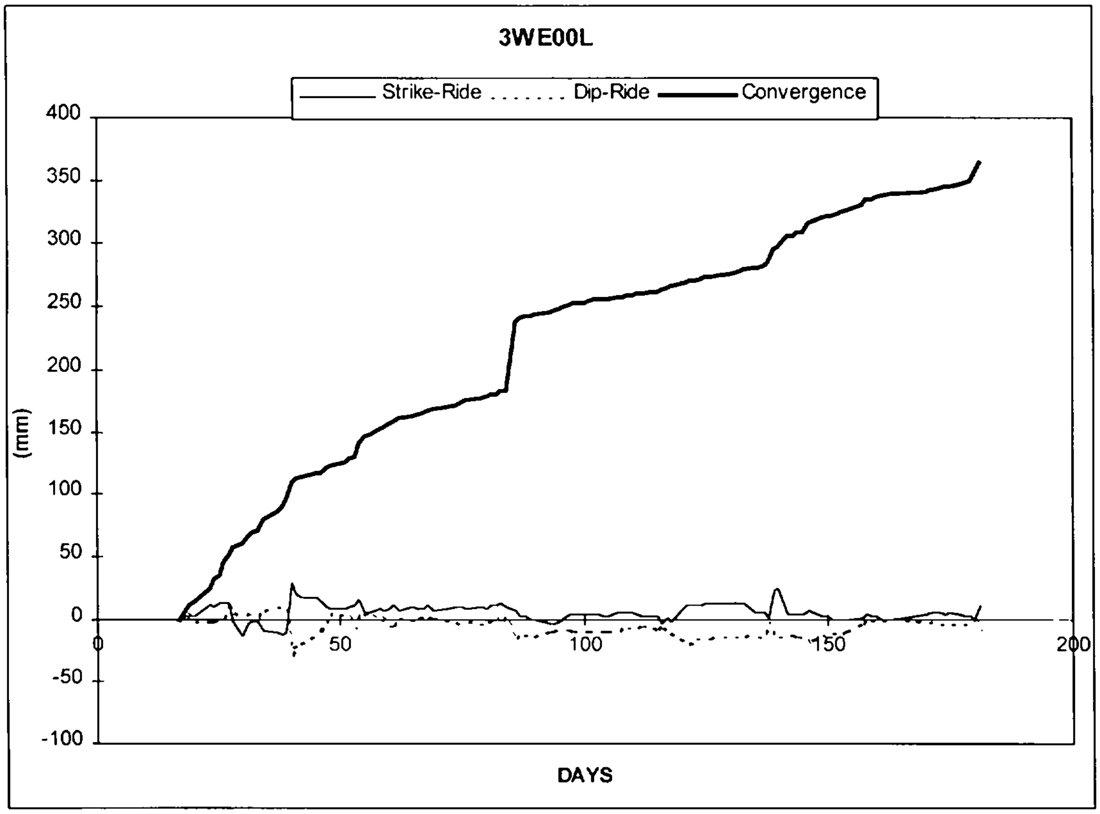


Figure 19 : Convergence-ride measurements at stations 35 & 36 (Refer to Figure 1).



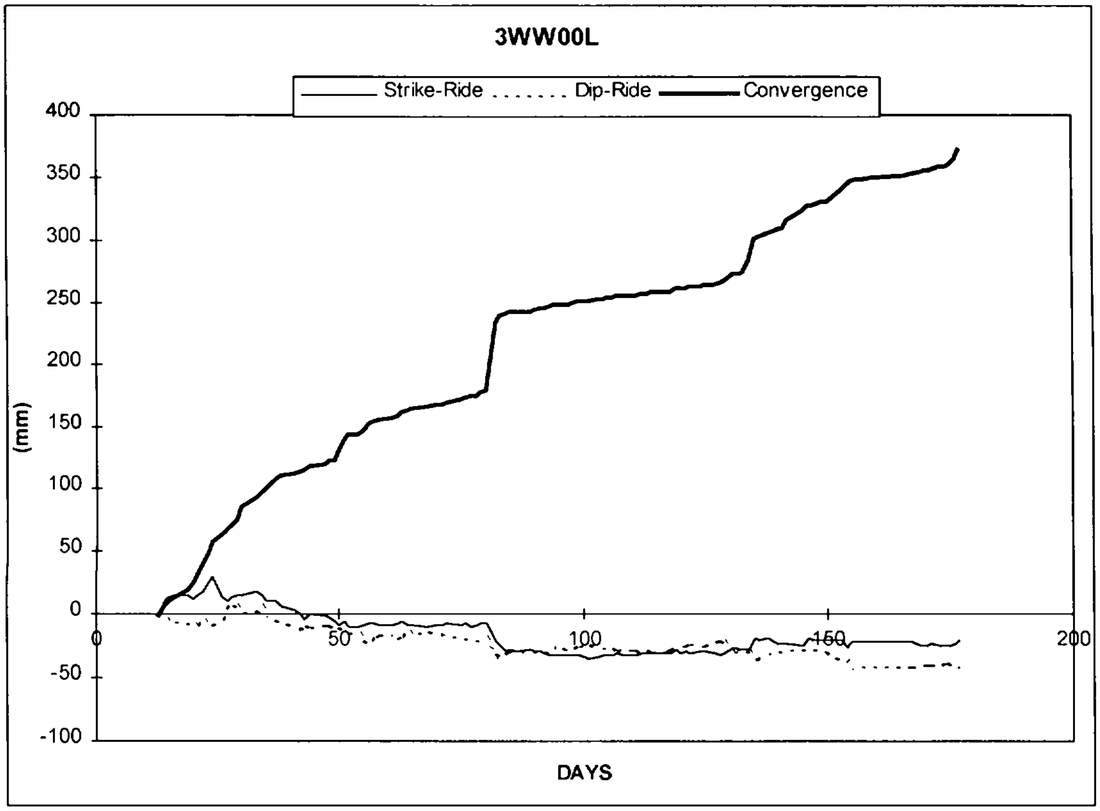


Figure 20 : Convergence-ride measurements at stations 37 & 38 (Refer to Figure 1).

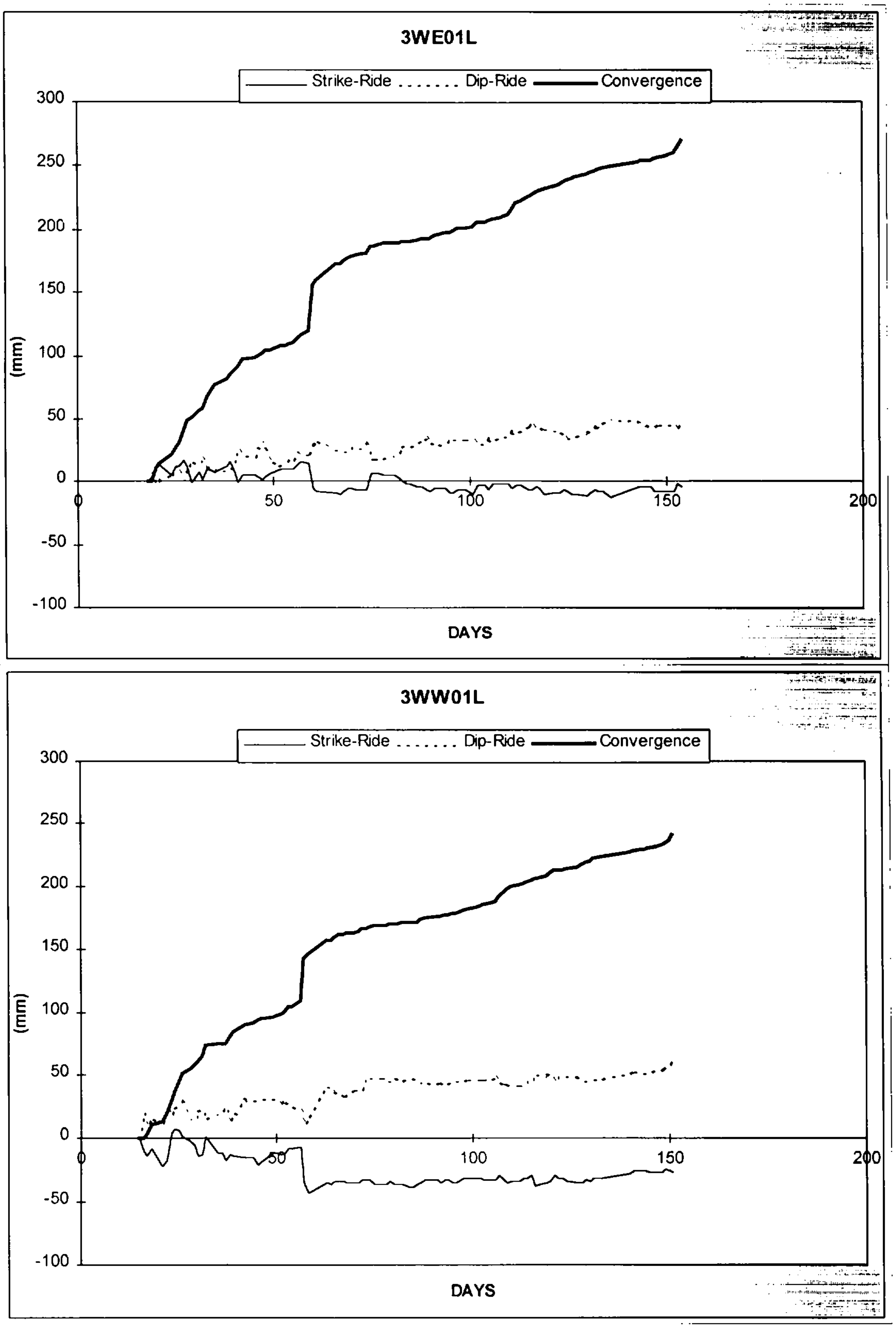


Figure 21 : Convergence-ride measurements at stations 39 & 40 (Refer to Figure 1).

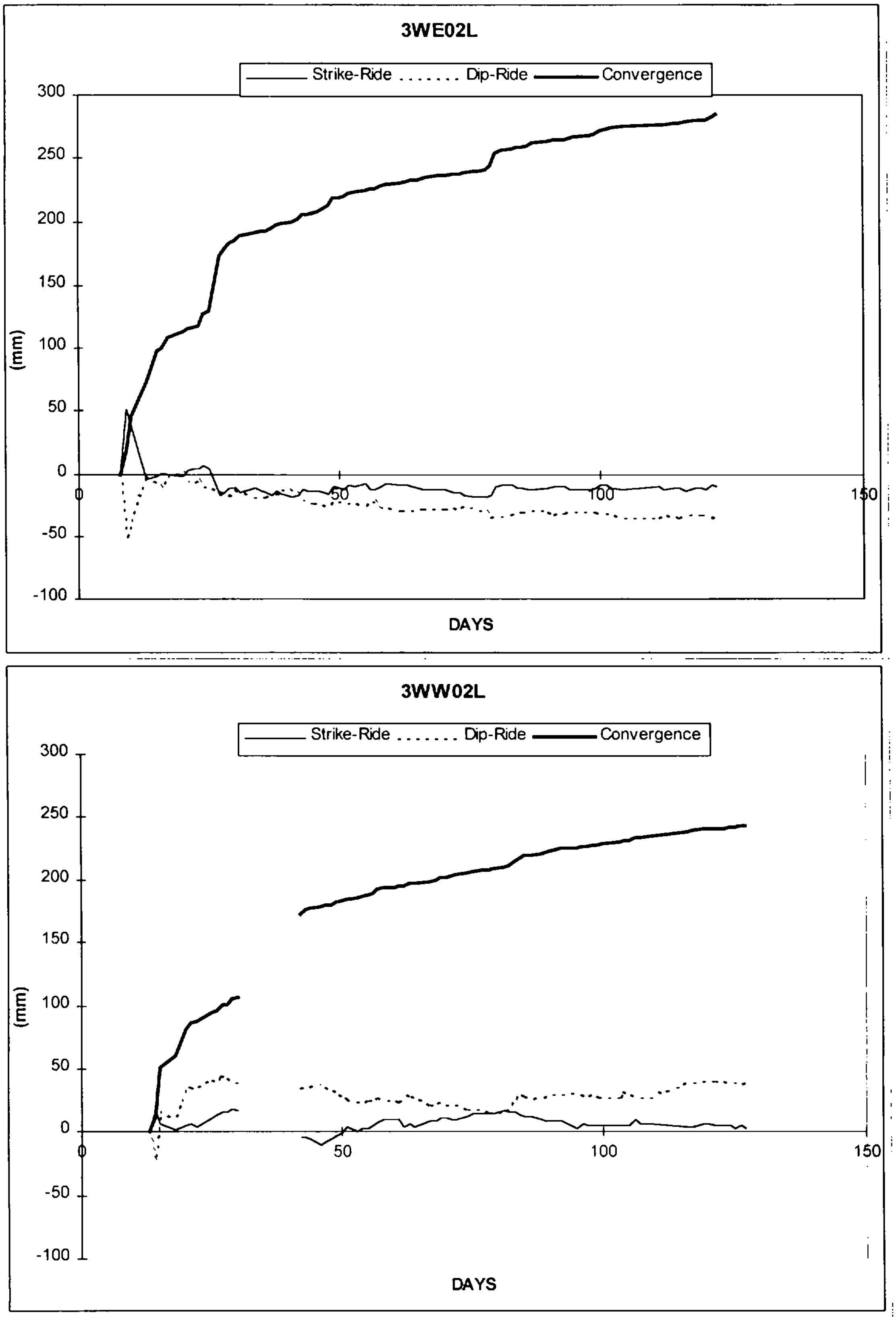
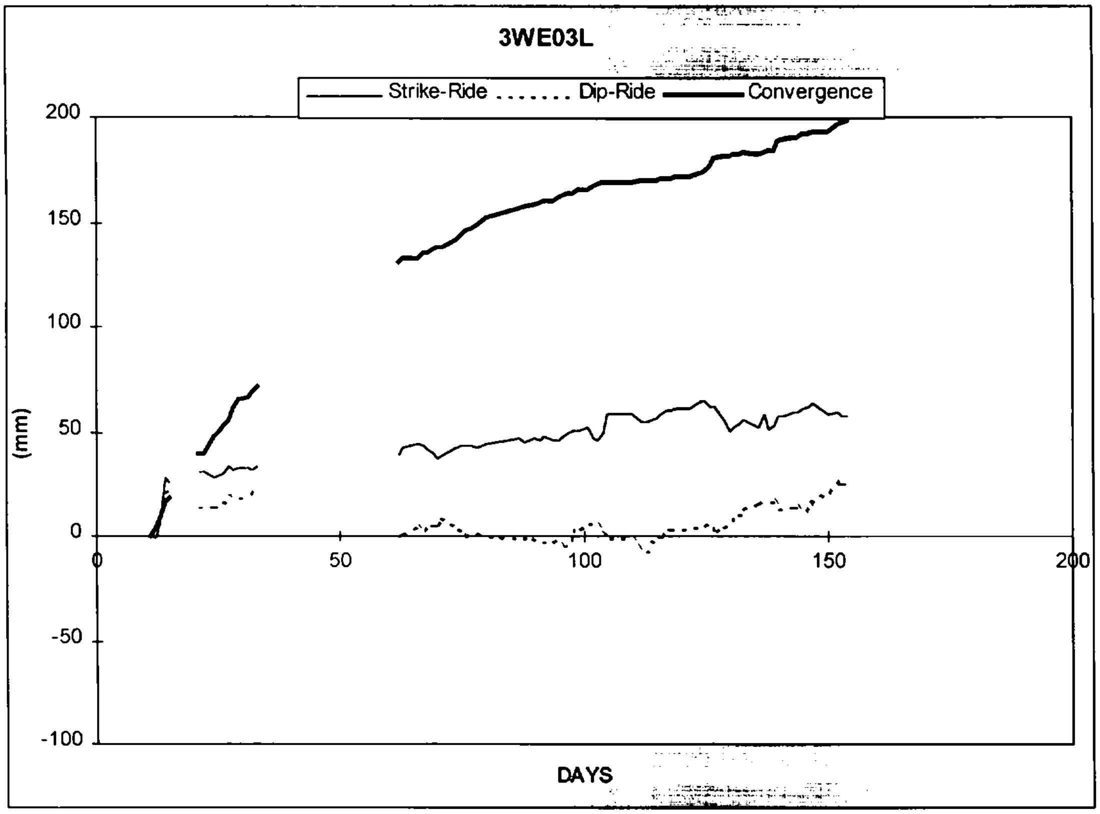


Figure 22 : Convergence-ride measurements at stations 41 & 42 (Refer to Figure 1).



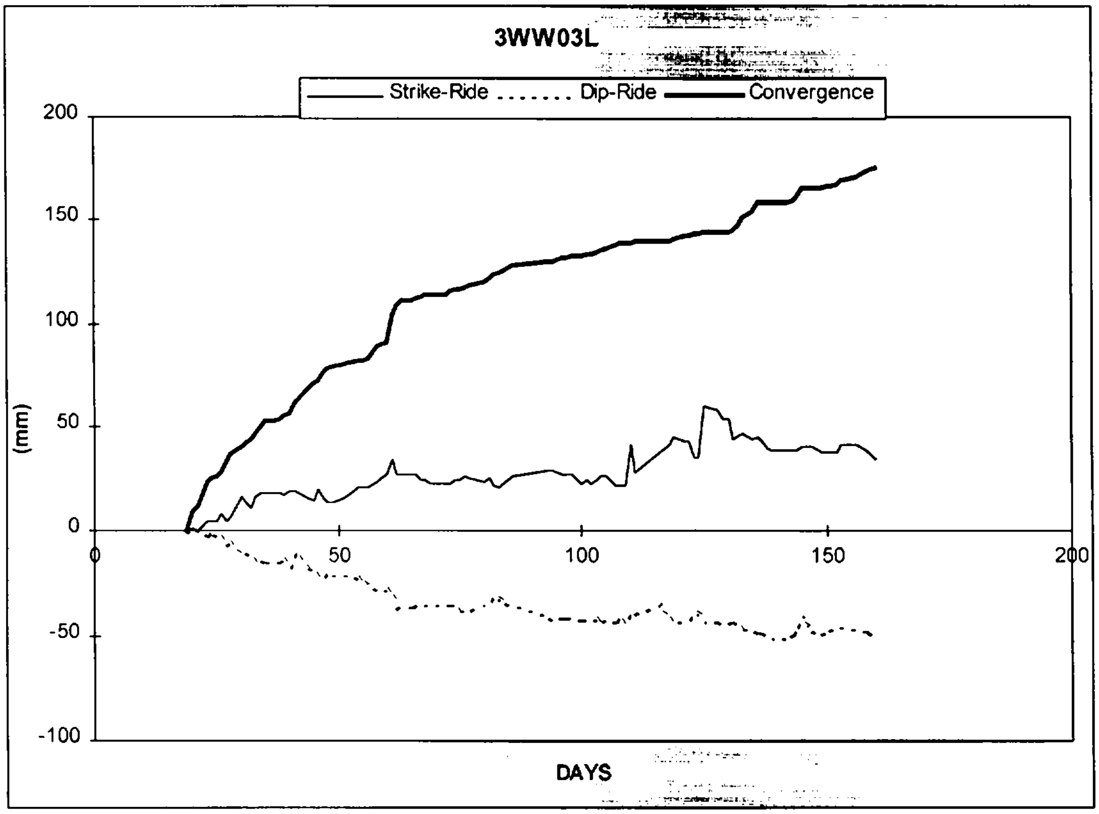
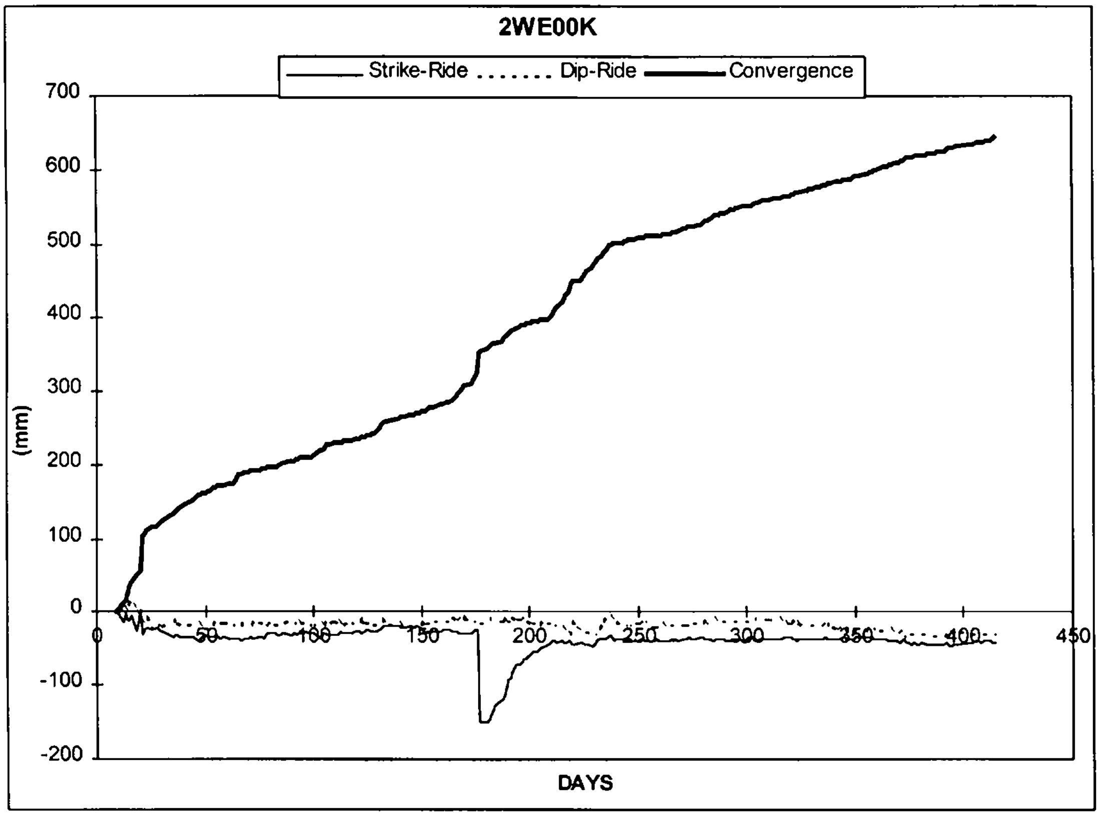


Figure 23 : Convergence-ride measurements at stations 43 & 44 (Refer to Figure 1).



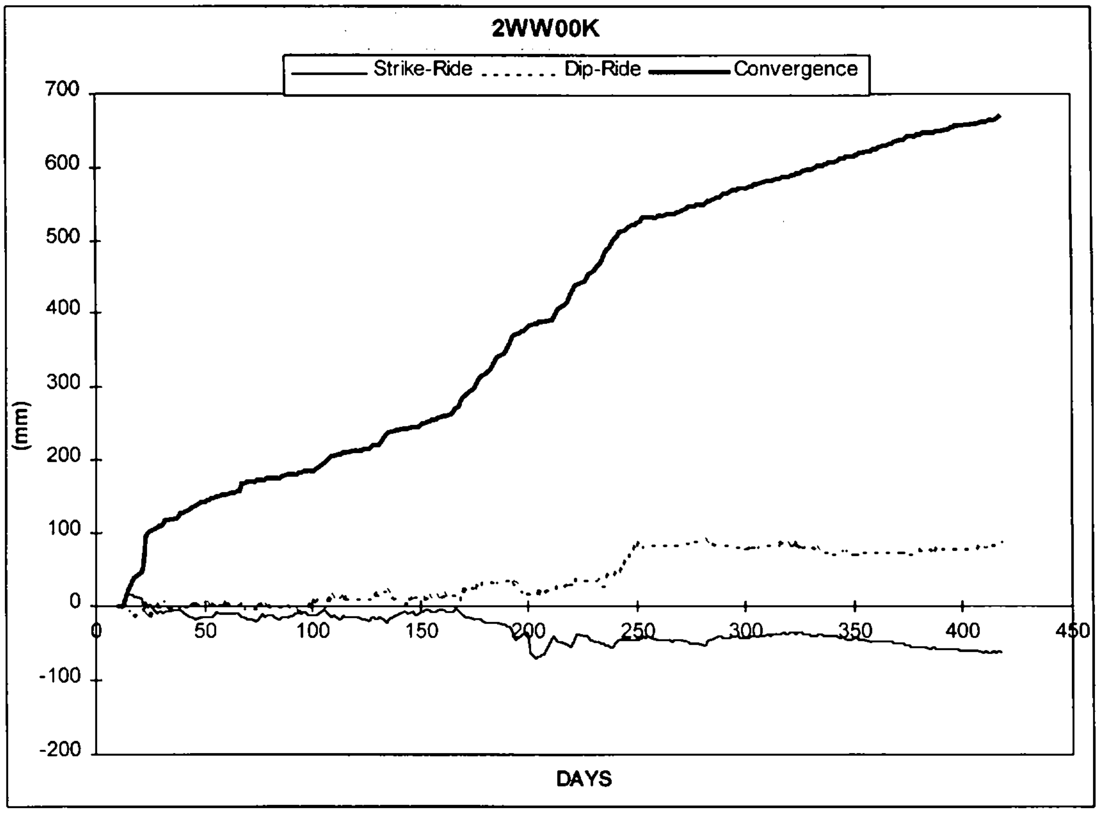
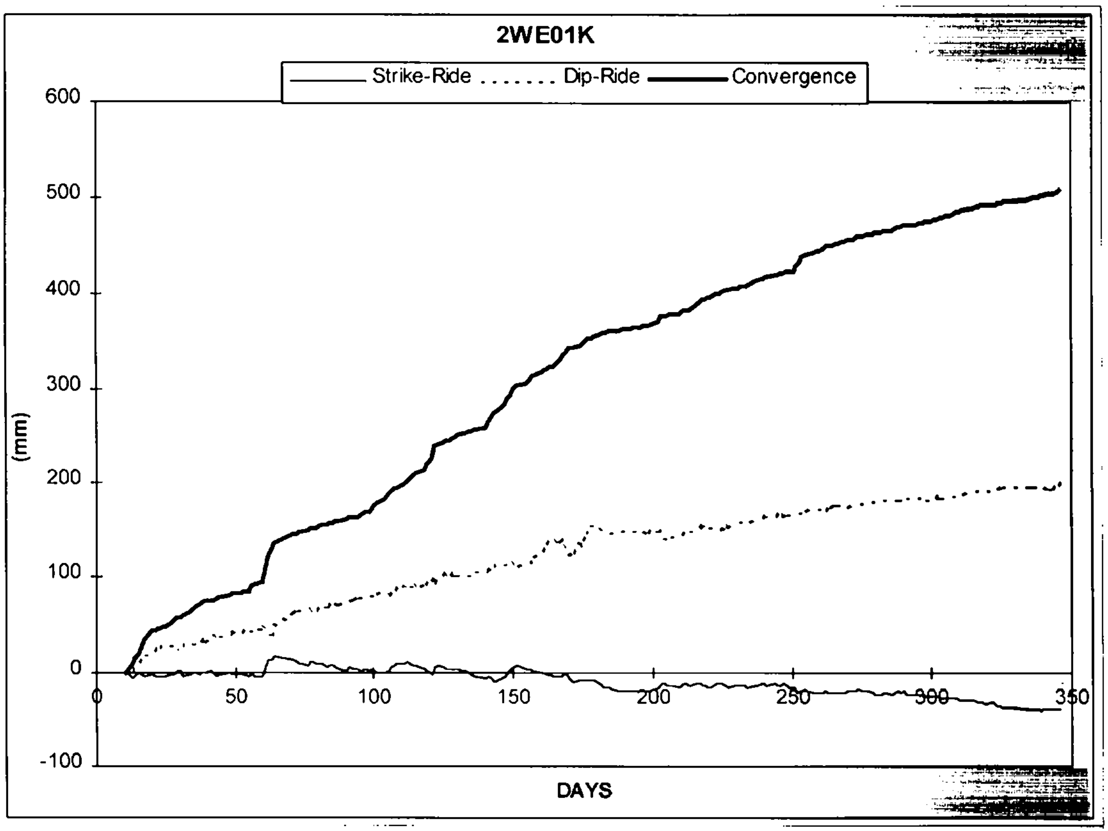


Figure 24 : Convergence-ride measurements at stations 45 & 46 (Refer to Figure 1).



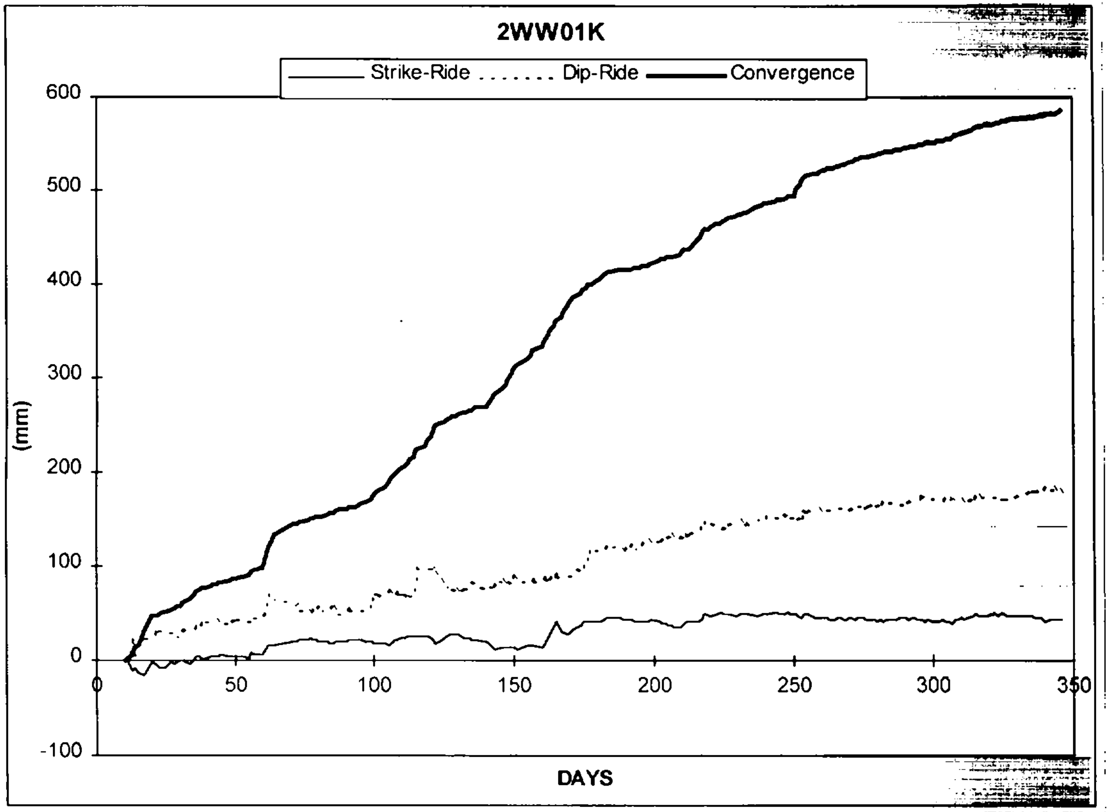
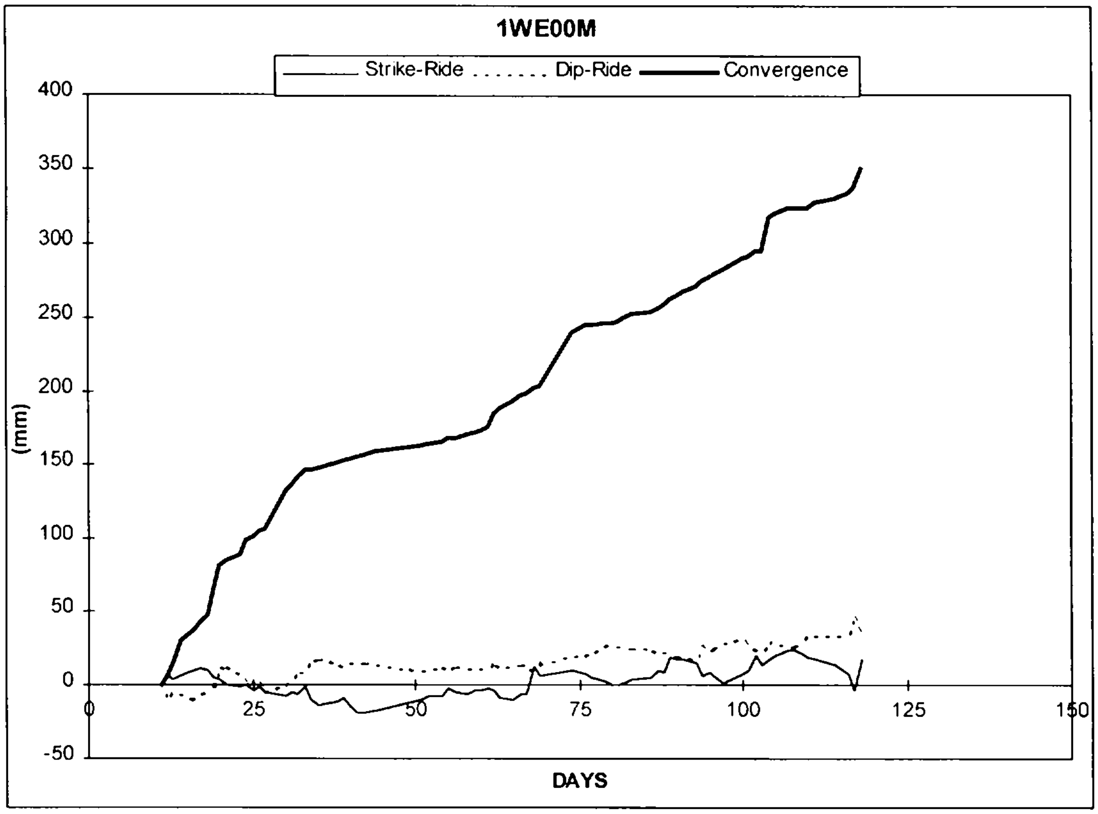


Figure 25 : Convergence-ride measurements at stations 47 & 48 (Refer to Figure 1).



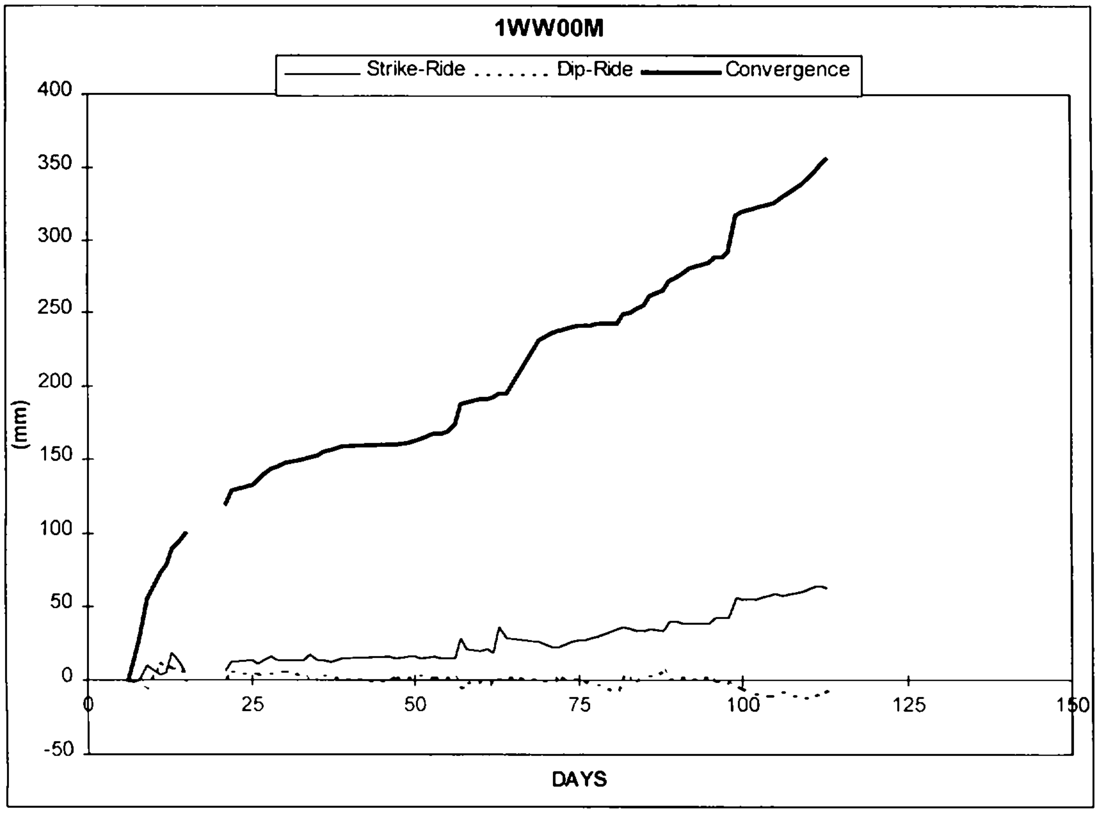


Figure 26 : Convergence-ride measurements at stations 49 & 50 (Refer to Figure 1).

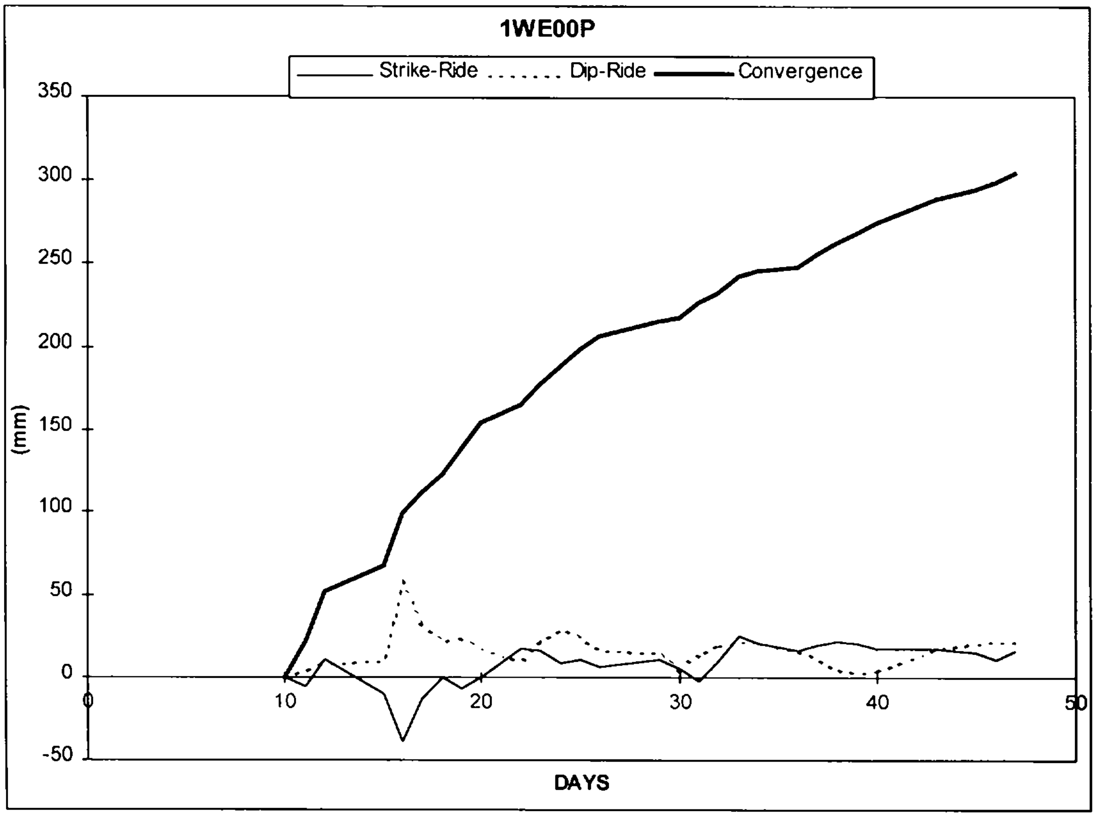


Figure 27 : Convergence-ride measurements at station 51 (Refer to Figure 1).

Appendix 2

Guidelines for face-parallel preconditioning

Introduction

In order to ensure minimal delays to production, a panel lead/lag situation must be designed to accommodate the drilling of large-diameter preconditioning holes, using a dedicated percussion drill rig (for example, a Seco S36). Mining advance in the direction of the main axis of the remnant pillar is ideal, as it results in the most consistent mining conditions throughout the pillar extraction programme. Individual panels should not exceed 20 m in face length, in order to facilitate the timeous drilling of face-parallel preconditioning holes. A satisfactory mining configuration for overhand panels is shown in Figure 1. To minimise the leads between panels required to accommodate drilling equipment, the percussion rig should be installed at the face of the leading panel with hydraulic prop support (with headboards) on all sides. If the stoping width does not allow this, the footwall-lifted gully should be advanced to the face (with a possible cubby) for the setting up of the drill rig.

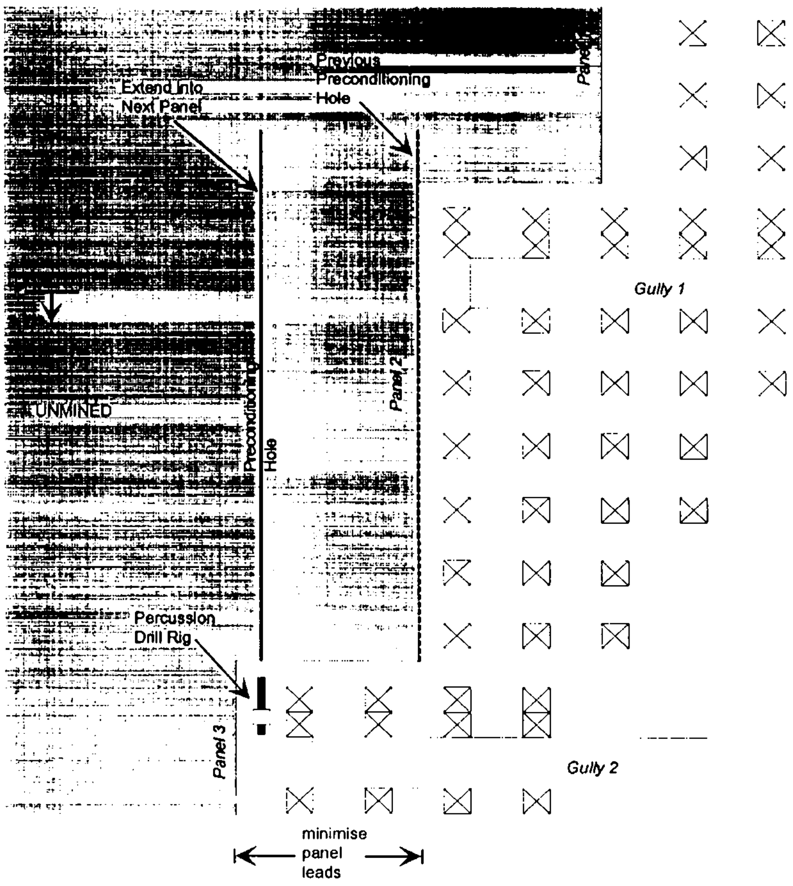


Figure 1: Preconditioning layout in an overhand mining sequence.

Panel 2 has been mined to limit (the previous preconditioning hole) and the next hole is drilled up to 5,5 m from the current face.

◆ Drilling of preconditioning holes

The hole should be drilled parallel to the reef plane along the reef/footwall contact, in the fracture zone that naturally develops ahead of the advancing face, and should extend into the rock mass ahead of the panel above (Figure 1). Holes must be kept parallel to the face to ensure a consistent preconditioning effect along the entire length of the face. Each hole should be inspected after completion of drilling to verify the hole direction. Severe deviations can cause inconsistent blast results.

It is important to ensure that the hole is not drilled beyond the stress peak that exists ahead of the face. It is likely that difficulty will be experienced in keeping the hole open when drilling too far ahead of the face. The actual hole positioning will be site specific and will depend on both the state of stress ahead of the face (stress profile) and the size of charge being used. Experience has shown that blasts from 89 mm preconditioning holes have been effective when the holes are collared 3,5 m to 5,5 m ahead of the stope face. Limited experimentation has been conducted with 76 mm holes, but experience (from a fan-shaped layout at previous sites) suggests that these should be positioned not further than 4 m ahead of the face.

Figure 2 illustrates the effects of positioning the preconditioning hole. Blasting too close to the face will result in a minimal preconditioning effect and will cause severe damage to the face area. Beyond the optimum zone, there is an area within which a preconditioning blast can, in fact, redistribute stress back towards the face, resulting in stress conditions that could lead to a face burst. Seismic evidence and numerical modelling results have shown that such re-loading of the face can occur. Near the intact rock zone, the confinement stress is so high that the blast has no effect on the rock mass further away from the blast hole.

As the preconditioning process involves stress transfer from one portion of the rock mass to adjacent regions, a systematic sequence of preconditioning is important. The best results to date have been achieved when the sequence begins with the lagging panel in the stope and progresses down-dip towards the leading panel. For example, in a three-panel configuration, the sequence should be panels 1, 2 and then 3. One possible cycle to integrate preconditioning with production is illustrated in Figure 3. Out-of-sequence preconditioning should be avoided, as it can result in increased stress concentrations on adjacent panel faces, rather than decreased stresses.

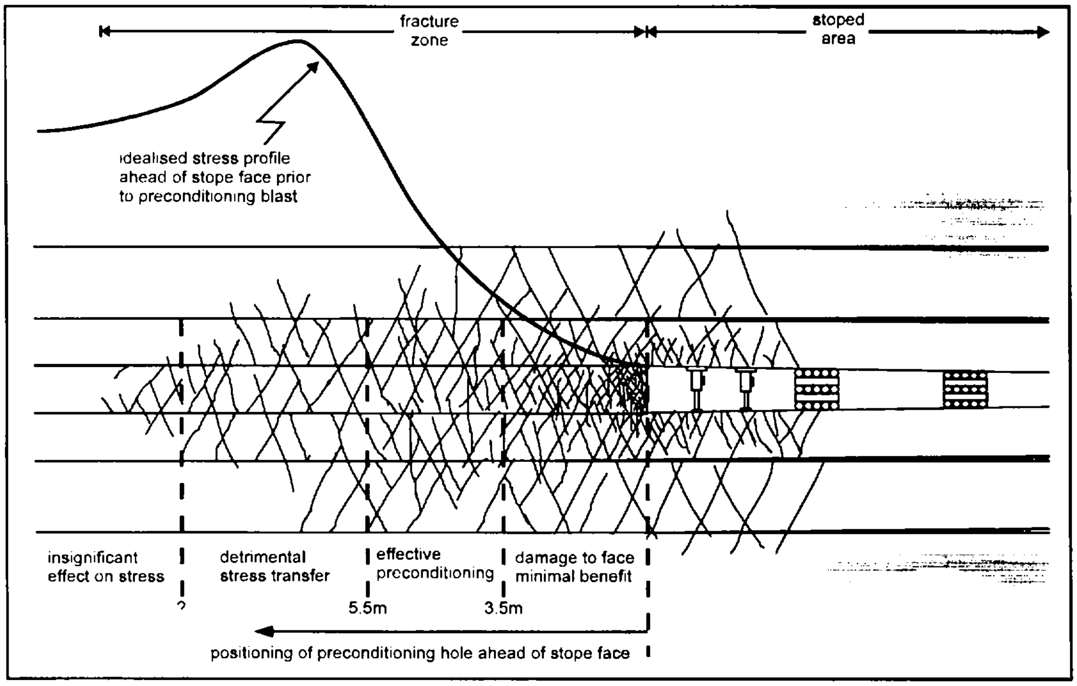


Figure 2: Effects of positioning an 89 mm diameter preconditioning hole at varying distances ahead of the stope face.

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

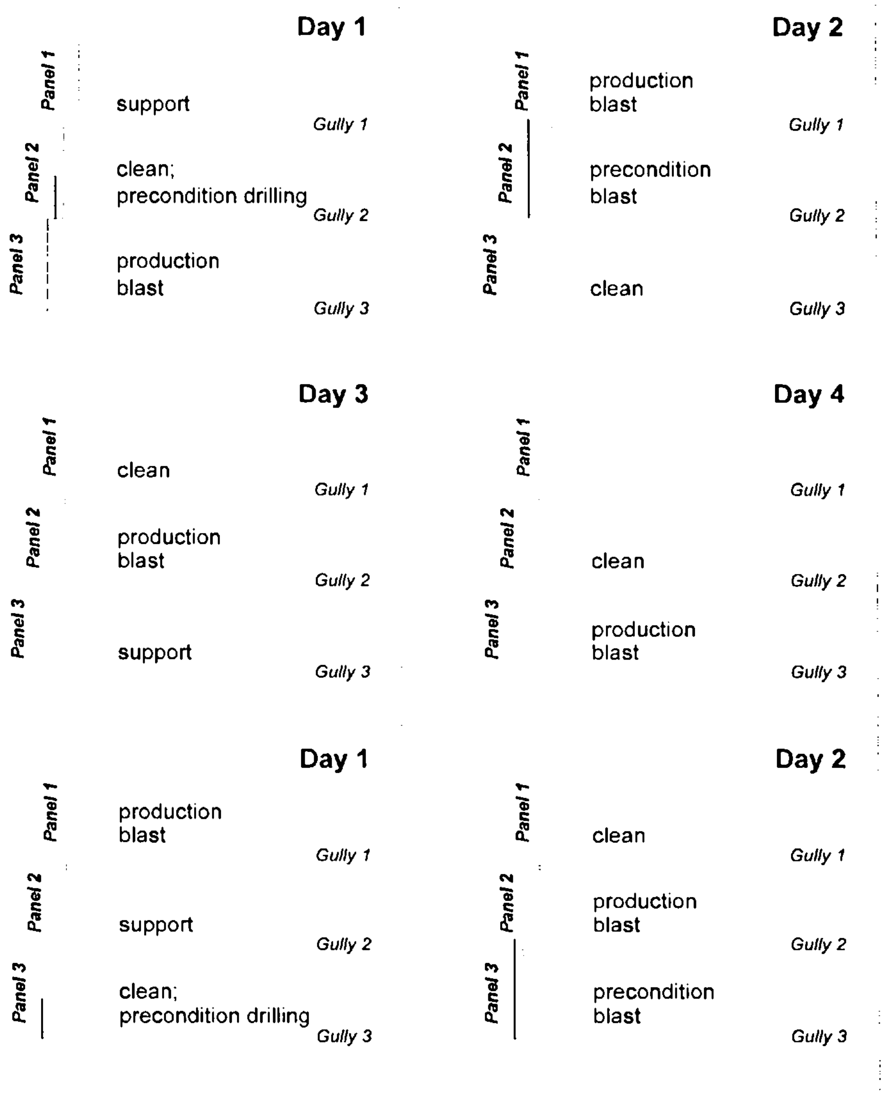


Figure 3: Example of a sequence of production and precondition blasting in a three-panel layout.

A four-day preconditioning cycle has been integrated into a three-day production cycle. A production blast is taken every day and the face is cleaned on the following day, with support being installed every second blast per panel.

◆ Charging of preconditioning holes

The purpose of preconditioning is to allow movement to take place along pre-existing fractures, where blocks in the rock mass have locked up. There is currently no evidence to suggest that the blast generates new fractures further away from the blast hole.

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

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

◆ Stemming

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

It is recommended that 5 m of the hole should be stemmed, in order to avoid a blow-out from the collar of the hole. Best results have been achieved when 1 m of clay is followed by 4 m of crushed rock. Five metres of clay stemming have been used (when crushed rock was not available) with mixed results. Blow-outs were experienced and often resulted in damage to stope support.

The length of stemming required will depend upon several factors, but, from observations made in situations where the stemming did fail, it appears that the most vital factor relates to the depth of fracturing at the collar of the hole. To a lesser extent, other factors would include the ability of the gas to penetrate the fractured rock mass, the diameter of the hole and the detonation pressure within the blast hole. The length of stemming should be kept to a minimum, as this will maximise the charge length ahead of the face for uniform preconditioning. It is advisable to consider the use of face-perpendicular preconditioning holes in the area of the face adjacent to the stemming, to overcome any reduced preconditioning effect resulting from the presence of the stemming.

◆ Dealing with misfires

Precautions, such as the use of multiple detonators, should be taken to minimise the risk of misfires. Removable stemming and top-primed holes will both facilitate the removal of the primers should a misfire occur. To date, two preconditioning holes have failed to detonate, one as a result of water inflow from the rock mass (resulting in the ANFO becoming desensitised), the other as a result of a cut-off fuse (which probably occurred during the installation of stemming). In both cases, the stemming was easily removed and the holes were re-charged and blasted.

◆ Assessing the effectiveness of preconditioning blasts

An effective blast should reveal a 'bulking' of the face, with minor amounts of scaling (not ejection) from the face. Minor 'shake-out' of loose rock from the hangingwall is likely to occur, even if the area has been barred/made safe. Footwall heave indicates that the hole has deviated in the footwall towards the face and too much blast energy has been lost through the footwall, rather than being used to dissipate energy from ahead of the face.

The seismic efficiency of a blast (seismic energy released expressed as a percentage of explosive energy) is typically less than one per cent. A blast consisting of 100 kg of ANFO should generate a seismic event in the order of $M=1,0$. A well-executed preconditioning blast will typically result in a seismic event of $0,5 \leq M \leq 1,0$. If an event of larger magnitude is generated, then a simultaneous release of stored strain energy has occurred with the blast. If the blast triggers a large event, this is usually the result of the stress transfer that accompanies a successful preconditioning blast. This stress transfer is seen as a migration of microseismic events further ahead of the face and into other portions of the pillar.

Convergence (measured on the day after the blast, from convergence/ride stations) should generally be in excess of 15 mm within 2 m of the face of the preconditioned panel. Other panels in the vicinity of the blast will also usually show an increased convergence rate for the period of the blast. At this stage, it is unclear how this behaviour will differ in higher stoping width panels: the stabilising pillar project stope at BGM maintained a stoping width of less than 1 m.

◆ Blast optimisation

The optimum blast configuration will vary from one stope to another, but the general principles will not change. A compromise must be attained between blast size and the time required to achieve this blast. The bigger the blast, the more effective it can be in preconditioning the rock mass ahead of the face. It also allows for the hole to be positioned farther ahead of the face and so precondition more ground with one blast, resulting in a more efficient cycle. The drawback is in the increased time required to drill a larger hole and the difficulties of drilling in a more highly stressed environment. The beneficial effects of preconditioning appear to be transient in nature, so that the longer the time period between preconditioning blasts, the more strain energy may again accumulate ahead of the face. This seems to apply even if the face is not advanced for some reason.

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

There is an improved efficiency in the behaviour of the stemming within smaller diameter holes. Therefore, less stemming may be required in smaller holes than larger ones, so that a greater proportion of face length can be 'covered' by the charge length, resulting in more uniform preconditioning. However, this still needs to be evaluated.

Appendix 3

Guidelines for face-perpendicular preconditioning

recommended, as they eliminate the need to remove the drill-steels at the end of the shift for sharpening.

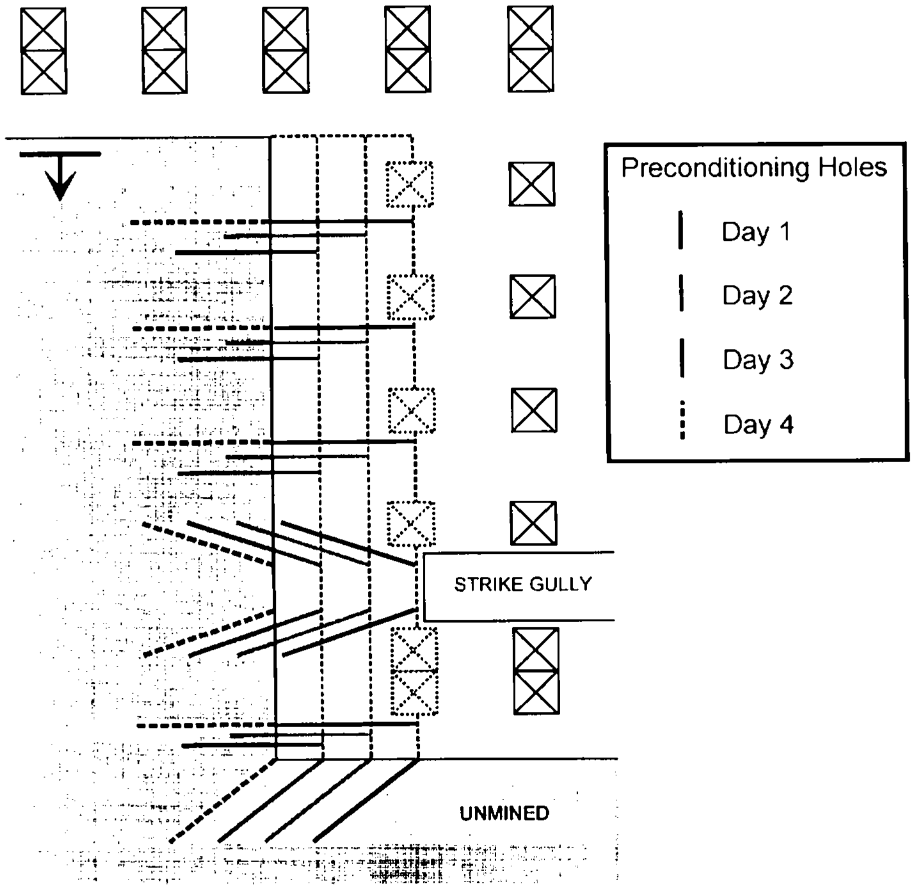


Figure 1: Diagram showing the face-perpendicular preconditioning layout for a three-day cycle. The maximum spacing between preconditioning holes is 3 m.

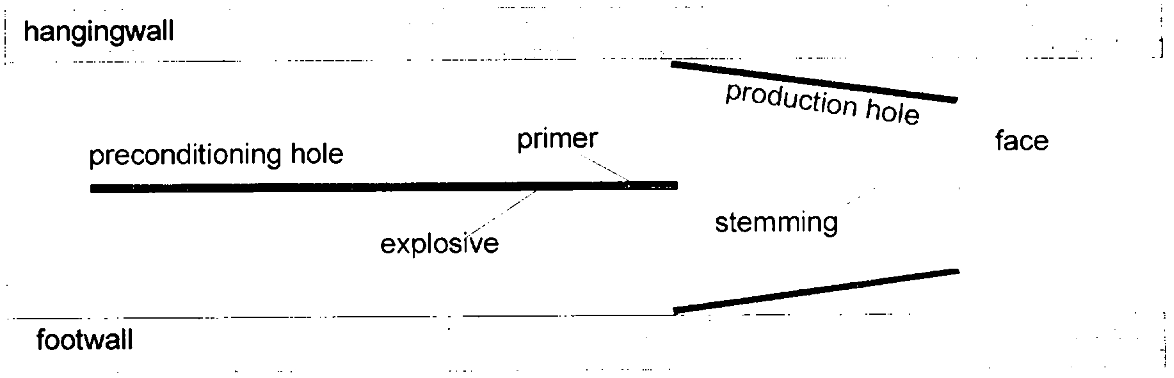


Figure 2: Cross-section ahead of the stope face, illustrating the relative positions of the production and preconditioning holes.

Timing of the drilling of preconditioning holes has shown that a single 3 m long hole can be drilled in about 15 minutes. Assuming that two machines are used to drill a 15 m face, this suggests that each drilling crew would require about one additional hour of work to drill three preconditioning holes. However, in practice, it has been found that the effect of the preconditioning is such as to reduce the drilling time per hole substantially. This reduction is sufficient to ensure that less time is required to drill a face with the additional preconditioning holes than was required to drill just the production holes, prior to the introduction of preconditioning to 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 drilling 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 then can a 3 m long hole be drilled without difficulty. It is, therefore, recommended that the first two or three preconditioning blasts be taken with 2,4 m holes, before drilling 3 m long holes.

Success in implementing this method of preconditioning is dependent on the willingness of the drill 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.

◆ Charging preconditioning holes

The purpose of preconditioning is to allow movement to take place along pre-existing fractures where blocks in the rock mass 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 need not generate additional fractures, but, rather, 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 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 with respect to pre-existing fractures and discontinuities. 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. Enough explosive must be used to charge 2 m of the hole, with the remainder being stemmed.

The detonation of preconditioning holes should be by top-priming the explosive charge, to facilitate removal of primers from misfired preconditioning holes (Figure 2). One emulsion cartridge is recommended as a primer and should be initiated with a Nonel (Figure 3) 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, due to the difficulty of obtaining the proper firing sequence of the preconditioning holes in relation to the production holes, this can be done when necessary. Where only standard ignition systems are available, the tie-up configuration for an acceptable firing sequence is shown in Figure 3. 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 (i.e. before the neighbouring production holes fire).

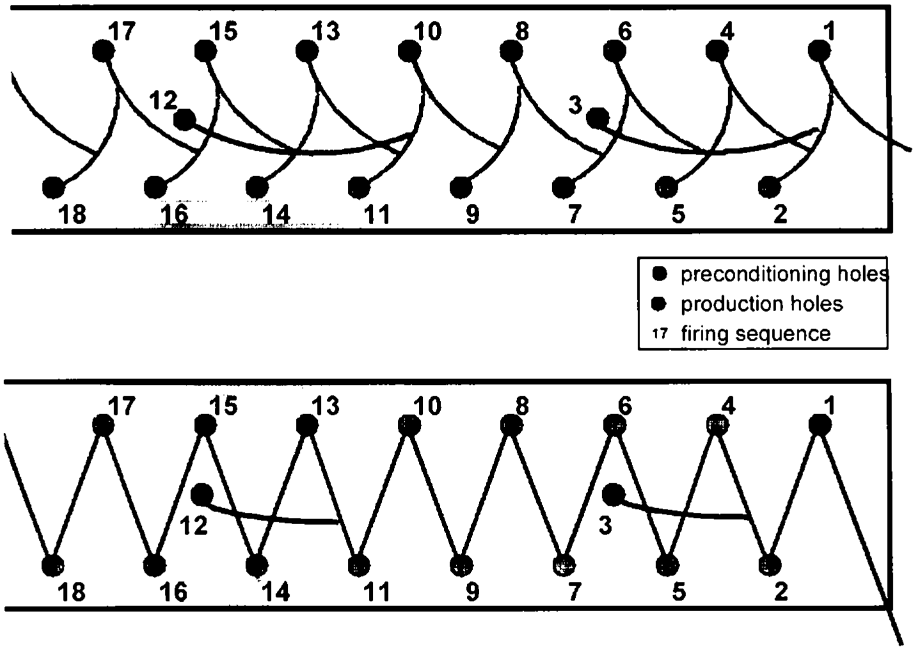


Figure 3: Example of the recommended tie-up configuration of Nonel (top) and fuse and igniter cord (bottom) for integrating the blasting of precondition and production holes.

◆ Stemming

Since 2 m of the preconditioning hole is charged, the remaining 1 m should be tamped with a competent stemming material. 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, the purpose of which is to contain the explosive energy in the hole for as long as possible The stemming also helps to protect the downline to the detonator and ensures that the primer stick 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.

◆ Handling of misfires and sockets

In addition to the requirements of examining 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 misfire), and (in the case of a socket) plugged. Since the preconditioning holes are drilled perpendicular to the face and in the middle of the stoping width, 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.

In the trials of face-perpendicular preconditioning to date, no preconditioning blast has resulted in the misfire of a production or another preconditioning hole. Only a few misfires have been 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 has been reported.

Appendix 4

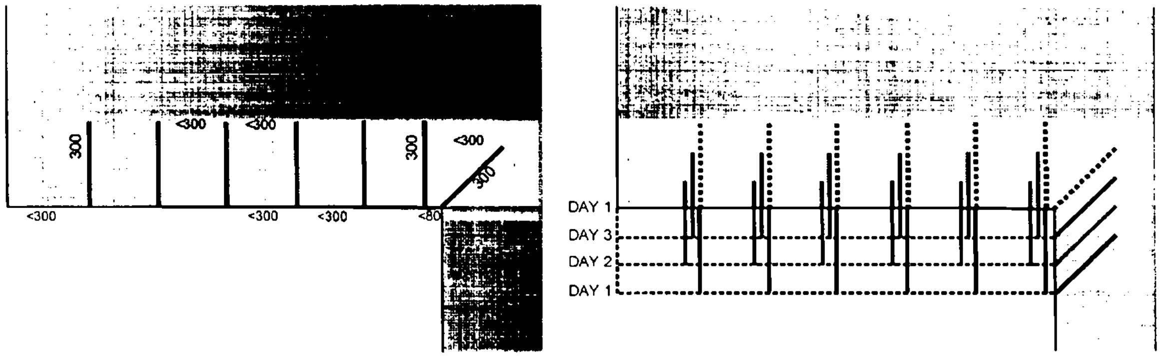
Sample standards for preconditioning that could be modified as required to incorporate into existing mine standards.

FACE-PERPENDICULAR PRECONDITIONING
HOLE LAYOUT
(FIGURE 1)

all measurements in cm

FRONT VIEW

SIDEVIEW



TOP VIEW

3 DAY CYCLE

KEY POINTS (Figure 1)

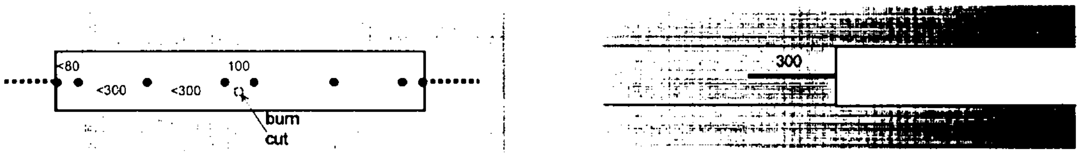
1. Mark all preconditioning sockets for easy identification.
2. All preconditioning holes are to be drilled at the mid height of the planned stoping width.
3. The spacing at the ends of the holes is to be no more than 300 cm.
4. All holes to be drilled at 90° into the stope face except
    - siding holes to be drilled at 45° into the stope face.
    - holes around a burn cut to be drilled 70° away from the burn cut (Figure 2).

FACE-PERPENDICULAR PRECONDITIONING

HOLE LAYOUT - HEADING

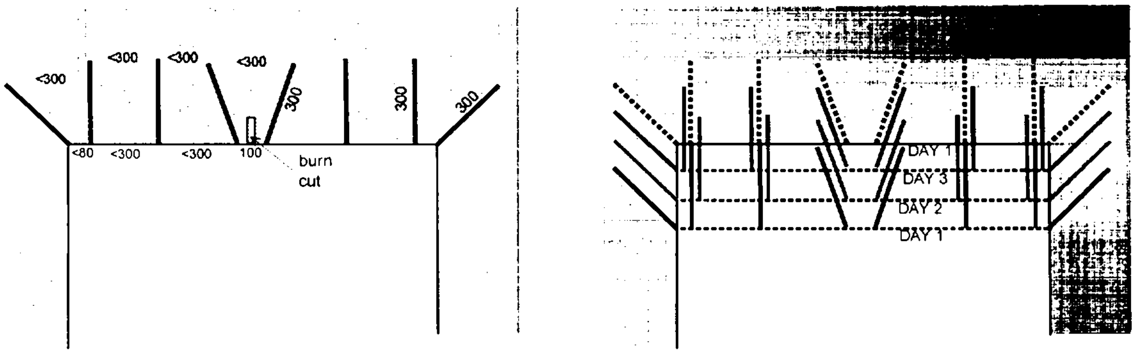
(FIGURE 2)

all measurements in cm



FRONT VIEW

SIDE VIEW

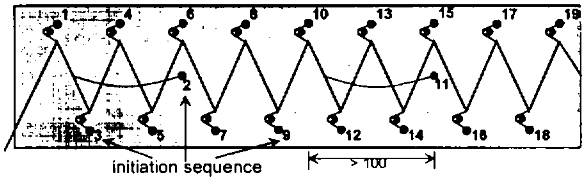


TOP VIEW

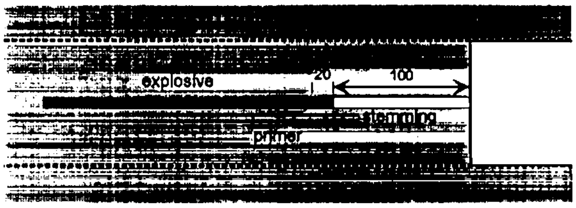
3 DAY CYCLE

FACE-PERPENDICULAR PRECONDITIONING
CHARGING AND TYING UP PROCEDURE
(Fuse and Igniter Cord)
AND INITIATION SEQUENCE
(FIGURE 3)

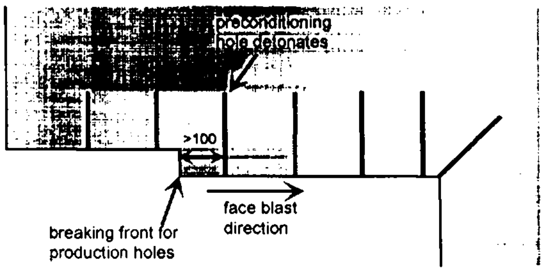
all measurements in cm



FRONT VIEW



SIDE VIEW



TOP VIEW

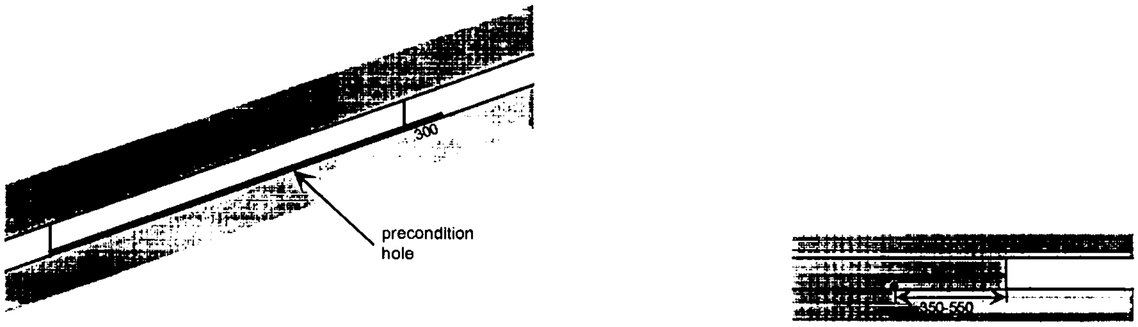
KEY POINTS (Figure 3)

1. Drill a 3 m hole into the face as in the key points of Figures 1 and 2 above.
2. Insert 180 cm of explosive into blast hole.
3. Insert the primer cartridge. The fuse length must be at least 2 m.
4. Insert another 20 cm of explosive.
5. Insert 100 cm of tamping material.
6. Fuses for production and preconditioning holes are to be all the same type and length.
7. Tie-up preconditioning hole fuses onto igniter cord at least 1 m ahead of the hole.
8. The preconditioning hole is to initiate at least 1 m ahead of the production holes.

FACE-PARALLEL PRECONDITIONING HOLE LAYOUT

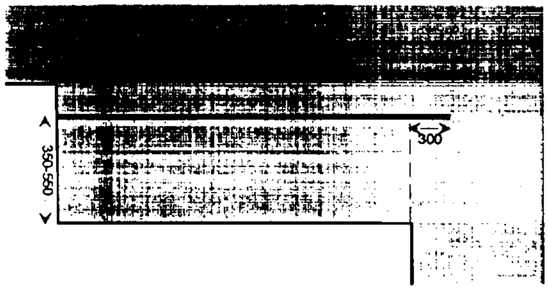
(FIGURE 4)

all measurements in cm



FRONT VIEW

SIDE VIEW



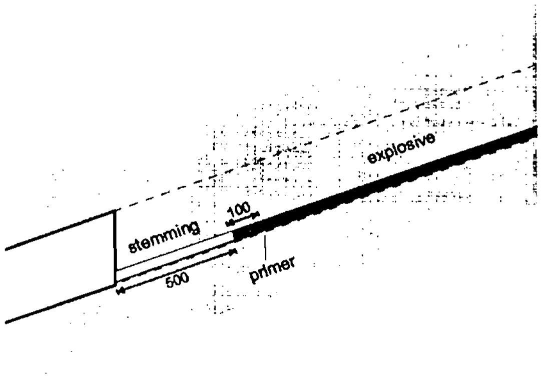
TOP VIEW

KEY POINTS (Figure 4)

1. 89 mm diameter preconditioning holes are to be drilled 3,5 m to 5,5 m ahead of and parallel to the stope face. (76 mm holes are to be drilled 3 m to 4 m ahead of and parallel to the face.)
2. Preconditioning holes are to be drilled at the dip of the strata for a length of 3 m longer than the face length of the panel.
3. Mining of this preconditioned face is not to proceed beyond this preconditioning hole until the next preconditioning hole has been drilled, charged and blasted according to points 1 and 2 above as well as in key points of Figure 5.
4. The time between preconditioning blasts shall not exceed 4 weeks for any producing panel.

FACE-PARALLEL PRECONDITIONING
CHARGING UP AND BLASTING PROCEDURES
(FIGURE 5)

all measurements in cm



FRONT VIEW

KEY POINTS (Figure 5)

1. No production blast is to take place on the same day as a preconditioning blast in the same panel.
2. Drill the preconditioning hole according to the key points of Figure 4.
3. Explosives are to be placed into the blast hole up to 6 m from the collar of the hole.
4. Insert the primer into the hole and place firmly against the explosives. The primer will consist of a Nonel or electric detonator.
5. Place another 1 m of explosives into the hole.
6. The last 5 m of the hole is to be tamped with a suitable material.
7. The preconditioning blast is to be manually detonated after the shift at least 1 hour before the production blast from adjacent panels.
8. If a preconditioning hole misfires, no production blast is to take place in neighbouring panels.
9. All face-parallel preconditioning holes are to be indicated on the 1:200 stope sheets immediately after the blast.

Appendix 5

Description of education and training scheme

◆ Introduction

In this section, the instructor would 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 (face bursts). 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 face burst problem

Preconditioning would generally be applied to face burst-prone areas, so that the workforce will usually be familiar with the face burst 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 rock mass immediately ahead of the advancing stope faces and that the rock mass bursts when these stresses exceed the capacity of the rock mass to contain them. The face burst problem is the physical manifestation of high face stresses: what is needed is some means of reducing the amount of stress acting on the stope faces.

❖ Preconditioning

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

The currently proposed mechanism for preconditioning has been formulated from a combination of direct underground observation and various measurements of the behaviour of the rock mass surrounding the excavation, as well as from numerical and physical modelling of preconditioning blasting. 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; also, the transmission of seismic energy through the buffer zone from more distant larger events is reduced and, hence, the likelihood of damage to the stope resulting from such events (whose incidence is clearly not itself directly affected by the preconditioning) is reduced.

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 work-load 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 which 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) 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 rock mass surrounding the excavation.

❖ Face-perpendicular preconditioning

Face-perpendicular preconditioning is well suited to normal production faces, such as in longwall and sequential grid stopes, 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 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 difficulties in practice and have not necessitated any compromise in the support system in the face area to date.

The preconditioning holes would be stemmed for a distance equal to the length of the production holes, to ensure that the energy from the explosion is contained within the hole and imparted to the surrounding rock mass. The preconditioning holes are blasted as part of the production blast, timed to ensure that there is at least 1 m of burden for each individual preconditioning shot.

❖ 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 more effective than the face-perpendicular method for dealing with the exceptional stress environments encountered in these areas and as 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 rock mass 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. Additional measures should be considered to try to minimise this effect, as discussed in Section 4.3.3 of this report.

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 which is further ahead.

◆ Implementing preconditioning

In this section, the instructor would 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.

❖ 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 face burst 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 preconditioning 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, convergence-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. These could be measured after each blast from fixed points in the stope (e.g. support elements or convergence-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 being 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 convergence-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. Convergence-ride data can be acquired fairly cheaply, but the acquisition of useful seismic data obviously presupposes the installation of an adequate seismic network.

Convergence-ride measurements would typically be carried out by an observer on a daily basis; various continuous convergence measuring devices (e.g. clockwork closure meter) are also available and allow one to determine the instantaneous convergence 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 convergence 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 rock mass via an actual