RR 37/87

CHAMBER OF MINES OF SOUTH AFRICA
RESEARCH ORGANIZATION

CAUSES OF FALLS OF HANGINGWALL OVER GULLIES ADJACENT TO STABILIZING STRIKE PILLARS

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RESEARCH REPORT NO. 37/87 (Amended)
PROJECT NO. GR2P
AUGUST 1987

KEYWORDS: ADVANCE HEADINGS
FALLS OF GROUND
GULLIES
PILLARS
REEF PILLARS
STRIKE GULLIES

PREFACE

The introduction of strike stabilizing pillars in longwall mining situations, as a means of reducing the energy release rate and, hence, the incidence of rockbursts, has been accompanied on some mines by hangingwall control problems in gullies immediately up-dip of the pillars. The occurrence of falls of hangingwall in these gullies causes considerable problems in handling rock and materials, and also constitutes a serious hazard to workers. Work on finding a solution to this problem is being carried out under the Chamber of Mines research programme for the development of improved support methods in the stoping area. It appears that the main cause of the hangingwall control problems is severe hangingwall fracturing over the gullies, as a result of the geometry of the pillar - gully - stope layout. A solution to the problem may include modifying the mining layout and improving the gully support. This could lead to safer working conditions as well as reduced production losses through better hangingwall control. However, further work is required if the optimum mining layout for this area of the stope is to be determined.

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SUMMARY

This report will be of interest to rock mechanics engineers and mining personnel who are concerned with the occurrence of falls of ground in strike gullies.

Falls of hangingwall over strike gullies on the up-dip side of strike stabilizing pillars in longwall mining systems were investigated. Gullies were examined in both the Carletonville district and on the East Rand. Falls of hangingwall were logged and the nature of the detachment surfaces, which allowed the rock to fall, were identified.

In the Carletonville mines the falls were due to the development of closely spaced fractures sub-parallel to the hangingwall, over 10 m wide advance headings mined on the up-dip side of the pillars. Together with the usual face-parallel fractures and occasional joints these hangingwall-parallel fractures bound unstable hangingwall blocks.

The presence of numerous down-dip inclined cross-beds in the hangingwall on the East Rand mine prevents the formation of hangingwall-parallel fractures over these wide advance strike gully headings, which accounts for their greater stability.

Reduction in hangingwall-parallel fracture formation can be achieved by mining only the gully as an advance heading. The relatively narrow arch of fractures which develops can be stabilized by installing support tendons in the hangingwall of the gully face.

Fracturing developed in the sidewalls of the narrow advance headings may cause gully-sidewall instability allowing the sidewall to break away beneath gully-side packs.

Several systems of support over the gully are suggested as is an alternative method of developing a narrow advance heading, which may alleviate the sidewall slabbing problem. These should be tried to assess their practicability and effectiveness.

The prevention of hangingwall-parallel fracture development is likely to be more effective and less costly than any possible systems of gully-hangingwall support.

CONTENTS

LIST OF FIGURES

LIST OF FIGURES (contd.)

1 INTRODUCTION

Stabilizing pillars were first introduced for regional support purposes in deep gold mines at East Rand Proprietary Mines (ERPM) in the mid 1960's (Ortlepp and Steele, 1973). The experience with these pillars showed a reduction in rate of seismic energy release and associated rockbursts (Salamon and Wagner, 1979).

Stabilizing pillars were introduced in 1980 on Western Deep Levels (WDL) and Blyvooruitzicht gold mines in an attempt to reduce the incidence of rockbursts by reducing the volumetric convergence. Since their introduction, production losses due to the incidence of rockbursts, have decreased considerably (Bayley and Hagan, 1984), although production losses due to the incidence of rockfalls not attributable to rockbursts, have increased by about 50 per cent. (Figure 1). The location of fatal accidents attributable to rockbursts and rockfalls, since stabilizing pillars were introduced on Western Deep Levels seems to be closely related to the presence of these pillars (Figure 2). It can be seen that 38 per cent of accidents occurred within the first 10 m up-dip of the pillars, with a further 20 per cent in the next 10 m up-dip. It would appear therefore that some serious destabilization of the hangingwall has occurred on the immediate up-dip side of these pillars.

The investigation reported here was undertaken to determine the causes of this hangingwall instability. Conversely it was also considered necessary to ascertain why at ERPM, where stabilizing pillars have been used for many years, marked instability of gullies adjacent to these pillars has not been apparent.

On all three mines investigated the practice has been to carry a 9 m wide heading immediately up-dip of the pillar abutment. This heading is usually advanced 5 to 10 m ahead of the stope face and the scraper gully into which the face scraper tips is excavated just up-dip of the middle of this heading. Support on the sides of the scraper gully (Figure 3) is either by 0,8 x 1,6 or 1,1 x 2,2 m packs built at 1,6 m (skin to skin) spacings. Down-dip of the gully south-side pack another pack is built with

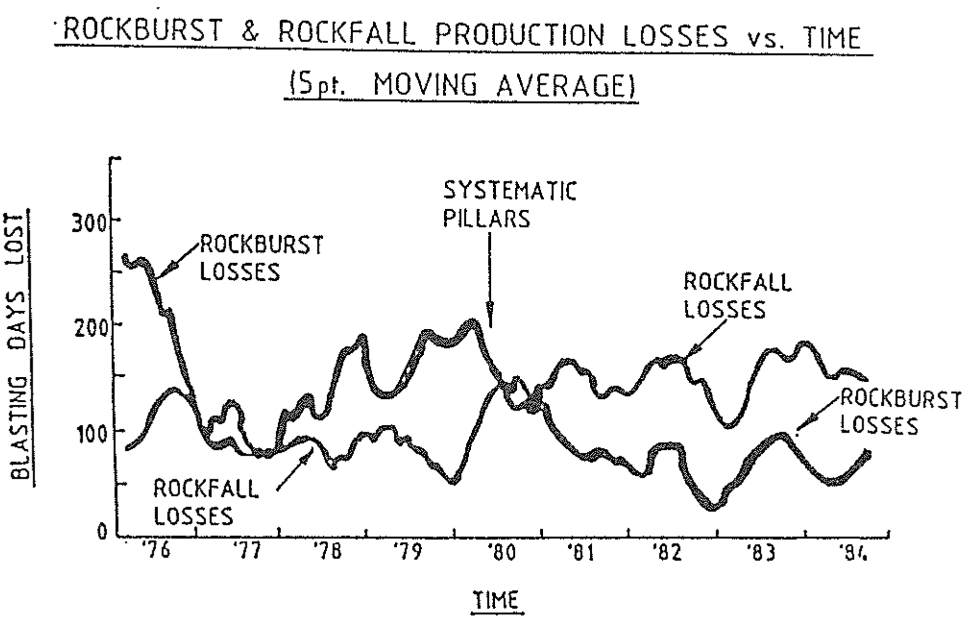

Figure 1 PRODUCTION LOSSES ATTRIBUTABLE TO ROCKBURSTS AND ROCKFALLS ON WESTERN DEEP LEVELS (BAYLEY AND HAGAN, 1984)

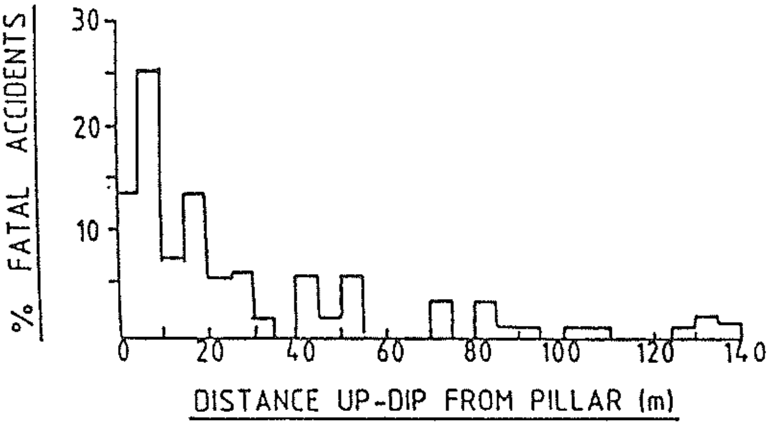

Figure 2 LOCATION OF FATAL ACCIDENTS ATTRIBUTABLE TO ROCKFALLS RELATIVE TO THE POSITION OF PILLARS (BAYLEY AND HAGAN 1984)

dimensions 0,8 x 1,6 m or 1,1 x 1,1 m. Hydraulic props or other elongate supports are sometimes used between the gully side packs just ahead of the stope face.

1.1 Falls of Hangingwall Over Gullies

As with all the other falls of hangingwall, falls over gullies depend on the presence of two or, more usually, three orientations of intersecting detachment surfaces separating the rock that is likely to fall from the rock that remains in place. Rock slabs between face-parallel fracture surfaces in a hangingwall act as beams which are capable of supporting themselves between the packs on either side of the gully. Therefore, any detachment surfaces which cut across these beams have a detrimental effect. Parting planes or hangingwall-parallel fractures cut the slabs into thinner beams which break more readily, while steep detachment surfaces such as poorly cohesive joints, which cut across the slabs, facilitate breakage of the beams. These steep transverse surfaces separate the beams of rock from the direct influence of support elements. Detachment surfaces such as cross-bed partings and a range of faceward inclined fractures can, by intersecting steep fractures or joints, form wedges of rock which are particularily likely to fall. Low inclination (± 20°) faceward-dipping fractures are common ahead of weakly cohesive, face-parallel joints.

Since gullies provide the access and travelling ways for men and materials, their hangingwalls must remain intact and stable along the working length of the gully for extended periods. They are usually unsupported over widths of about 3 m and are in use along strike lengths of 60 m to 100 m. Over a gully therefore, there is a strong possibility that hangingwall rock, which is transected by detachment surfaces with unfavourable orientations, will fall while the gully is in service.

2 INCIDENCE AND EXTENT OF FALLS OVER GULLIES ADJACENT TO PILLARS IN THE CARLETONVILLE AREA

The hangingwall of Carbon Leader Reef stopes on Blyvoortuitzicht and Western Deep Levels gold mines is generally very similar both as regards the rock type present and the types and orientations of geological structures occurring. Falls could be expected, and indeed were found, to be influenced by lithology and structure in very similar manner on both mines. They are therefore considered together. The geology of the stope hangingwall on ERPM is very different from the Carbon Leader Reef hangingwall.

Twelve gullies next to solid abutments of stabilizing pillars have been examined in Carbon Leader stopes on Western Deep Levels and Blyvooruitzicht gold mines. Significant falls of ground had occurred along the working length of all except one of the gullies examined, namely 108½-47 E3 escape gully on Western Deep Levels. Many of these areas were considered still to be potentially hazardous. The reduced horizontal constraints within the hangingwall, resulting from the initial falls, had made subsequent extensions of the falls likely.

As an illustration of the extent of the falls, several gully hangingwall profiles are depicted in Appendix II. The proportion of the gully length over which the hangingwall had fallen was commonly about 30 per cent but reached 70 per cent along one Blyvooruitzicht gully. Individual falls were usually 4 m or more in length, with a width in the dip direction ranging from the width between the gullyside packs (1,5 to 3 m) to the width of the heading (8 to 10 m). Figure 3 indicates the typical areas of falls that have been observed. The areas of falls are shaded and the packs that have had to be rebuilt are hatched.

The smaller falls had usually fallen out to a height of a metre or less above the initial hangingwall. Larger falls had commonly fallen out to the base of the Green Bar (1,5 to 2 m up). Occasionally the falls extended up into or through the Green Bar (3,5 or 4 m up) to expose the hangingwall of Green Bar quartzite. Along a 40 m stretch of 104-38 W1 gully on Western Deep Levels, 100 per cent of the gully hangingwall had fallen to a height of between 2 and 4 m (Figure 4) and from 2 to 4 m up-dip of the gully down to the pillar abutment.

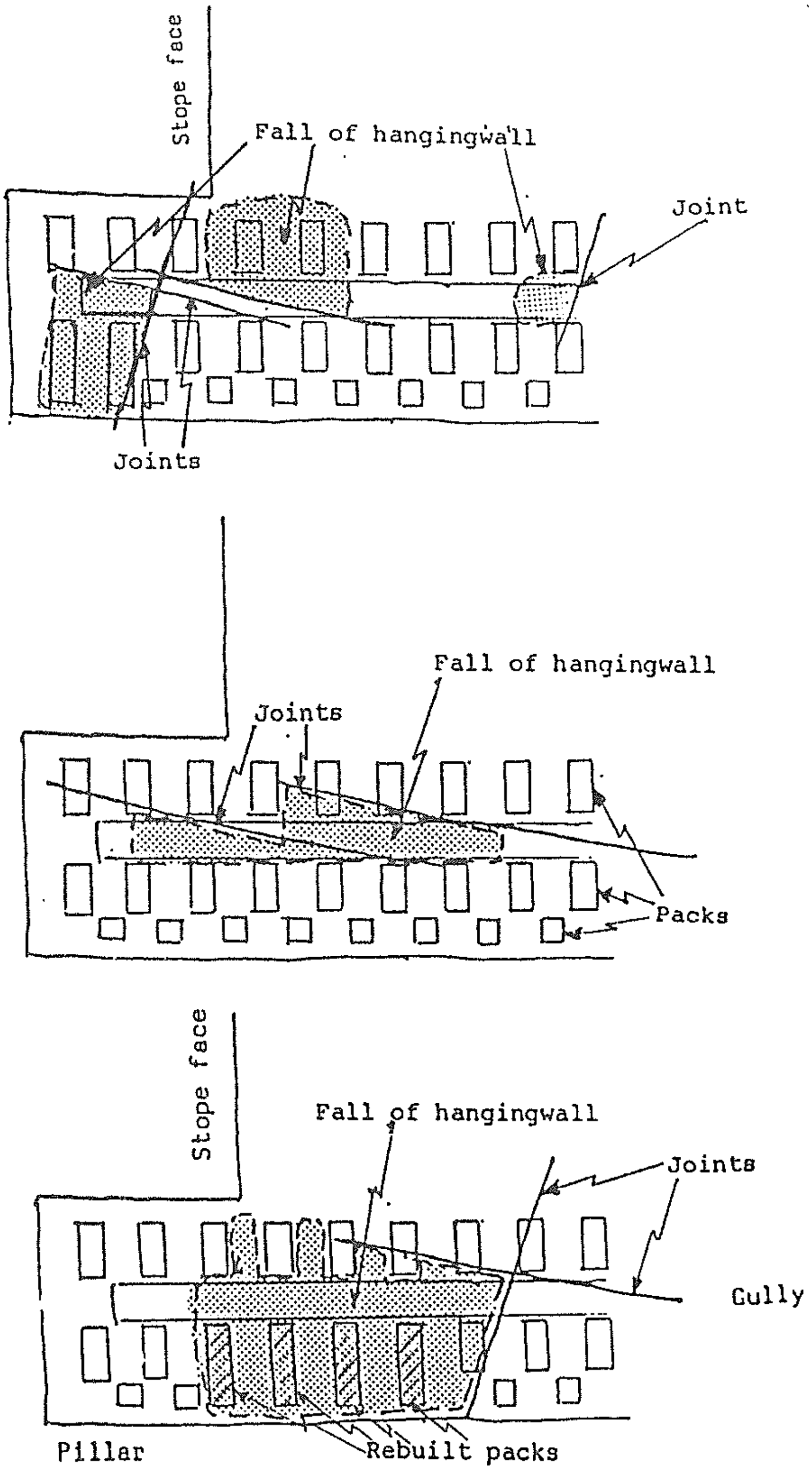

Figure 3 COMMON FALL OF GROUND GEOMETRIES AND DISTRIBUTIONS, WITH RESPECT TO GULLIES AND WIDE HEADINGS ADJACENT TO STABILIZING PILLARS

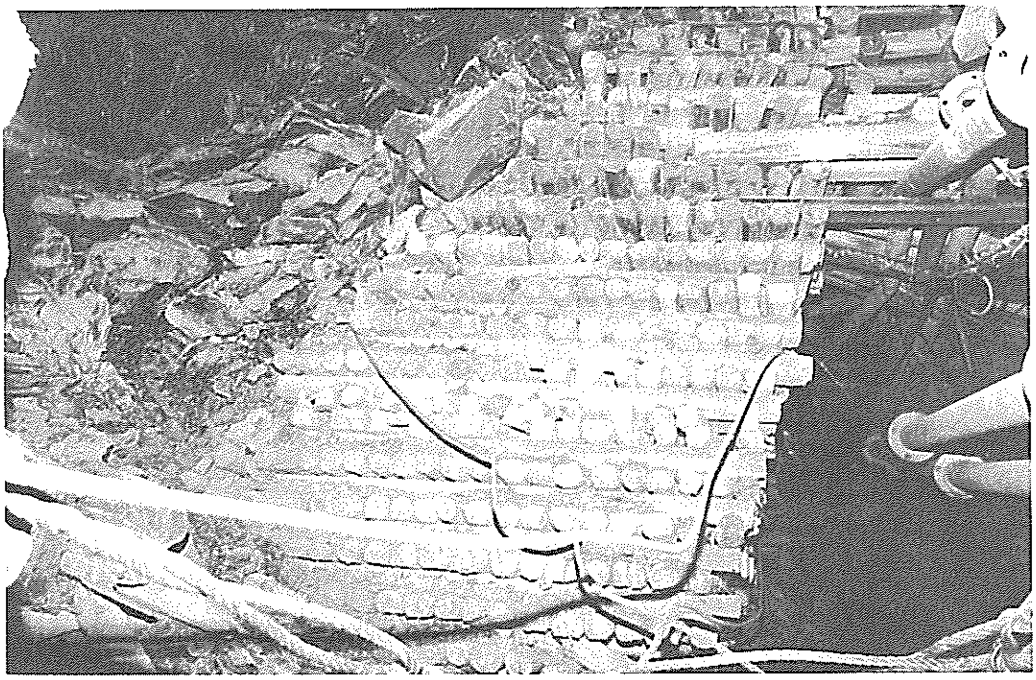

Figure 4 PART OF THE 40 m LONG FALL OF HANGINGWALL ALONG THE 104-38 W1 GULLY ON WESTERN DEEP LEVELS

Although much of the fall of hangingwall occurred close behind the face some major falls occurred well back from the face. Some of these, such as the falls along 102½-58 W1 gully on WDL, were related to a seismic event nearby. As can be seen from Figures 5 and 6 this seismic event dislodged rock which was already fragmented as a result of numerous fracture and joint surfaces. The rock fell between and around the packs most of which were still supporting the rock above them.

2.1 Detachment Surfaces that have Influenced Falls on Blyvooruitzicht and Western Deep Levels

Hangingwall-parallel fracture of face-parallel slabs was present at all except two fall sites. In these two sites as many as eight parting planes, within the lower-most metre of hangingwall, formed hangingwall-parallel detachment surfaces. Together with joints nearly parallel to the gully these partings had resulted in major falls of hangingwall along one gully on Blyvooruitzicht (Figure 7). Hangingwall-parallel fracture is more intensely developed over the gullies adjacent to and on the up-dip side of the strike stabilizing pillars, than elsewhere in the stope.

Figure 5 PART OF A MAJOR FALL DUE TO A ROCKBURST AFFECTING THE HANGINGWALL OF THE 102½ - 58 W1 GULLY ON WESTERN DEEP LEVELS

Figure 6 A VIEW SHOWING THE INCIDENCE OF HANGINGWALL-PARALLEL FRACTURING IN THE FALL ILLUSTRATED IN FIGURE 5

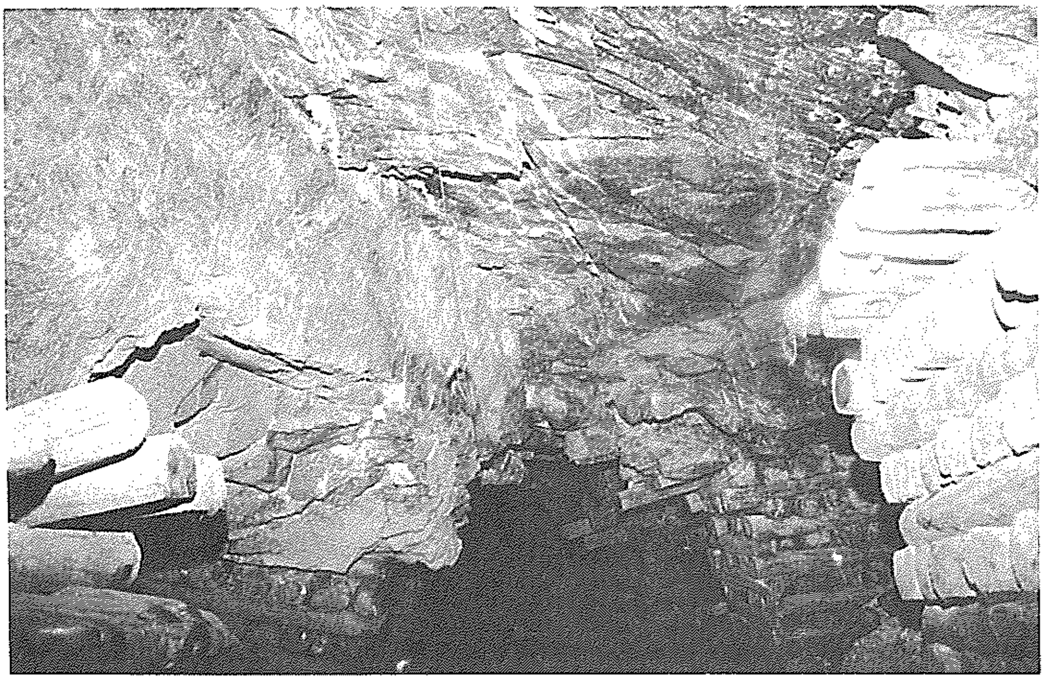

Figure 7 A MAJOR FALL ATTRIBUTABLE TO THE PRESENCE OF NUMEROUS POORLY COHESIVE PARTINGS AND TO THE PRESENCE OF JOINTING
The joint is to the left. The yellow parting surfaces can be seen on the hangingwall (11 W gully, B4 longwall, Blyvooruitzicht)

Fractures

It can be seen from the geometry of these hangingwall-parallel fractures (Figure 8), and in particular the way that they arch shallowly over the 8 to 10 m wide heading, that they form over the headings. These headings are carried up to 10 m ahead of the stope face (Figure 9). The fractures, which are commonly 50 mm or less apart, are extension fractures and are inferred to be the result of stress almost parallel to the hangingwall. This stress is believed to be due to the combined effect of high vertical stresses on either side of the heading which, as a result of the Poisson's effect and dilatation, act together to result in sufficient stresses in the heading hangingwall to fracture the rock. Examination of the surfaces of these hangingwall-parallel fractures reveals that the stress which formed them was parallel to the face-parallel slabs as well as parallel to the hangingwall.

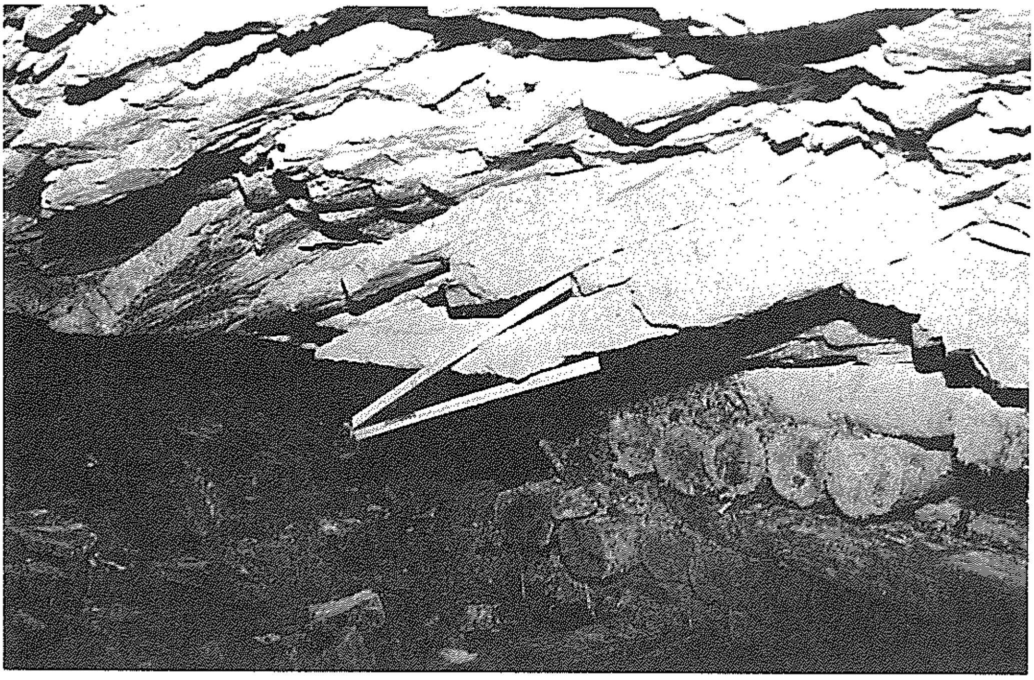

Figure 8 DOWNWARD-CURVING, HANGINGWALL-PARALLEL FRACTURES ON THE NORTH SIDE OF A WIDE ADVANCE HEADING
Base of rule is horizontal and the stope dips to the right.

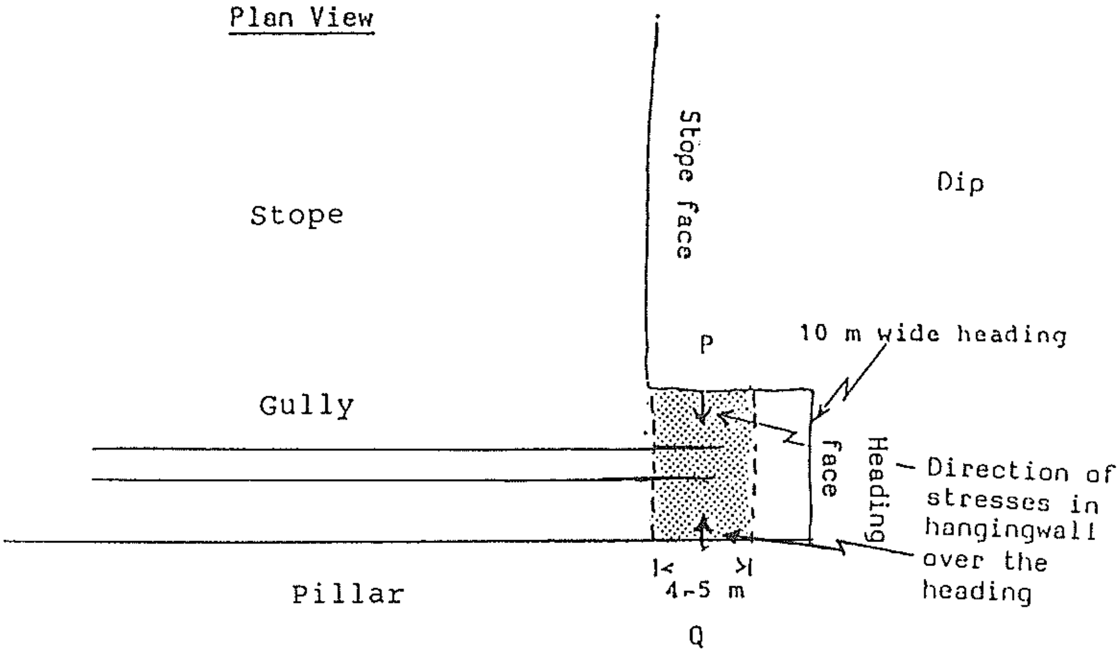

Figure 9 REGION IN WHICH HANGINGWALL-PARALLEL FRACTURES HAVE BEEN SEEN TO DEVELOP MOST ABUNDANTLY
High vertical stresses at P and Q result in stresses acting toward each other over the heading.

It is inferred from the aforementioned that the hangingwall-parallel stress acted most efficiently parallel to, and within the confines of, the fractures bounding each face-parallel slab. Hangingwall-parallel fractures appear to develop most abundantly over the section of the heading which lies within the 5 m immediately ahead of the stope face and have been seen as much as 1 to 2 m into the hangingwall. Where poorly cohesive joints occur sub-parallel to the face, low inclination (20°), faceward-dipping fractures may form just behind the heading face. Their formation seems to inhibit hangingwall-parallel fracture. Although these low inclination fractures also result in falls of hangingwall such falls are not extensive as they pinch out towards the face. Hangingwall-parallel fractures do not appear to develop where the lower hangingwall strata are thinly bedded or cross-bedded, with poorly cohesive bedding planes. However poorly cohesive bedding planes, being detachment surfaces, contribute to the likelihood of hangingwall-falls especially where they are closely spaced.

The proximity of a pillar with the high stresses developed in such an environment is not a pre-requisite for hangingwall-parallel fracture formation. These fractures are also developed over headings adjacent to strike abutments and headings being developed up-dip into strike abutments. They have also been found to develop quite prominently over the corners of some leading panels. In all these occurrences it appears that hangingwall-parallel stresses are generated in the abutments flanking a protruding portion of stope (a heading or a leading corner).

Joints

Two directions of joints were widespread and persistent with a generally uniform orientation in the siliceous hangingwall of Carbon Leader quartzite. Occurring either singly or in combination they constituted steep detachment surfaces which cut across the face-parallel and the hangingwall-parallel detachment surfaces and contributed significantly to the incidence of falls.

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The most easily recognized joint set, which is oriented about 20° to 35° right of the dip direction (and therefore of the face-parallel fractures), comprises near-vertical white-quartz veins with a veneer of black chlorite mica. This mica makes these joints very weakly cohesive and susceptible to shear displacement. Where these joints occurred alone they generally did not cause falls extending more than 2 to 4 m along the gullies.

The other joint set is oriented 15° to 30° right of strike and, therefore, at an acute angle to the strike gullies on Western Deep Levels. The westward-advancing diagonal gullies on Blyvooruitzicht, themselves about 10° right of strike, will tend to run even more closely parallel to these joints. The length of gully affected by each of these joints is consequently greater than that affected by the micaceous vein quartz joints, while the effected length along westward advancing gullies on Blyvooruitzicht is more than that on Western Deep Levels. This is because, the closer the strike of joints to that of the gullies, the more face-parallel slabs a single joint can intersect along a greater length of the gully. These joints can therefore result in falls more extensive than those due to the vein-quartz-filled and mica-veneered joint system which strikes across the gullies. Another feature of this joint set is that the surfaces of the joints are mostly very fine quartz crystals and slip on the joints is therefore unlikely, although they are weak in extension. These joints are very difficult to detect unless exposed by falls of ground.

2.1.1 Relative significance of detachment surfaces that have influenced falls

It has been shown in Section 2.1 that the development of numerous hangingwall-parallel fractures in the hangingwall quartzite over the headings is the major factor contributing to hangingwall instability adjacent to pillars. The two sets of joints that occur facilitate falls but, without accompanying hangingwall-parallel or low-inclination surfaces, they do not result in falls of hangingwall. The hangingwall-parallel fractures are so numerous and closely spaced that they result in thin, and therefore weak, face-parallel beams which break readily even in the absence of transverse joints.

A major unanswered question is why, sometimes, long stretches of gully hangingwall adjacent to the pillars remain intact. It has not been possible to see the amount of hangingwall-parallel fracturing in these intact hangingwalls because of the lack of falls. However, when the hangingwall of the 102½-58 W1 gully on WDL, which had previously been logged as intact, was brought down by a nearby rockburst, it was found to contain numerous hangingwall-parallel fractures. This suggests that the stretches of intact hangingwall lacked a motive force to cause them to fall, rather than lacking significant fractures. Further investigation of this matter is needed (see Section 4).

The incidence of closely spaced bedding-plane partings in the Carbon Leader hangingwall is insufficient to present a serious problem. Where they occur, however, they are a very significant cause of falls of hangingwall.

The presence of joints as prominent detachment surfaces, within fallen rock masses and bounding most falls, indicates that they are a common contributory factor to such falls. The correlation between joint orientations and the extent of falls is a further indicator of their significance. Because they intersect fewer face-parallel slabs over a shorter gully length, the micaceous quartz joints effect much shorter lengths of the gullies than do the joints of the more oblique joint set.

3 CONDITION OF GULLIES NEXT TO PILLAR ABUTMENTS AT EAST RAND PROPRIETARY MINES

Strike gully hangingwalls on ERPM were generally not affected by hangingwall-parallel fracturing. Two strike gullies on the up-dip side and one gully on the down-dip side of pillar abutments, were examined on the Main Reef Leader (Composite) Reef horizon at ERPM. Gully hangingwall conditions were generally as good as stope hangingwall conditions. Some minor falls (less

than 0,5 m high) were observed associated with cross-beds and one aided by a joint was seen. No hangingwall-parallel fracturing was observed. Face-parallel fracture was evident and the few falls that were seen were mostly attributable to the fall-out of wedge-shaped slabs between these fractures.

The hangingwall along all three gullies exhibited well developed cross-bed partings dipping across the gullies in a down-dip direction (Figure 10). It is inferred that in the presence of several of these surfaces, which are inclined at a low angle to the hangingwall, slip on the argillaceous cross-bed surfaces would relieve the hangingwall-parallel stress component. This would effectively prevent the stress reaching sufficient magnitude to induce hangingwall-parallel fracture. Hangingwall-parallel fracture was observed, however, over a slot being developed up-dip through the 75-74 pillar on the east of K longwall. Here, hangingwall-parallel stress could be inferred to have acted parallel to the up-dip advancing face and this would have been acting parallel to the strike of cross-beds.

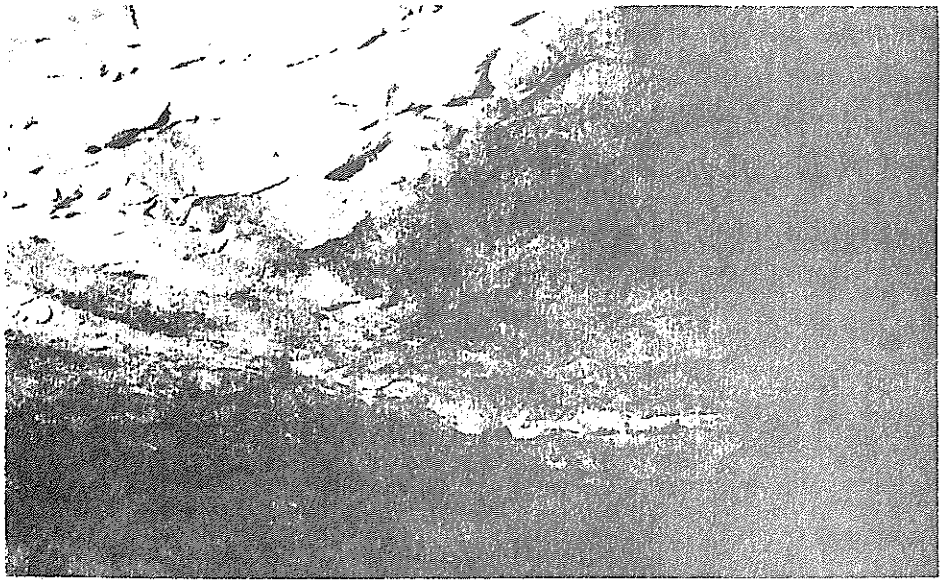


Figure 10 <u>VIEW ALONG A STRIKE GULLY ON ERPM SHOWING THE ABUNDANT CROSS-BEDDING DIPPING ACROSS THE GULLY</u>
This cross-bedding will prevent hangingwall-parallel fracture.

4 FORCES AND MOVEMENTS LIKELY TO AFFECT HANGINGWALL STABILITY ADJACENT TO STRIKE PILLARS

It has been found that in 20 m-wide strike pillars, fracturing with a strike-parallel orientation extends right through the pillars (Hagan and Grobbelaar, 1984). Furthermore it has been found that these pillars deform and displace the rock adjacent to them towards the stope (Figure 11, Brummer, 1984). It was found from measurement of displacements across steps in a borehole, drilled into the hangingwall next to a strike abutment,

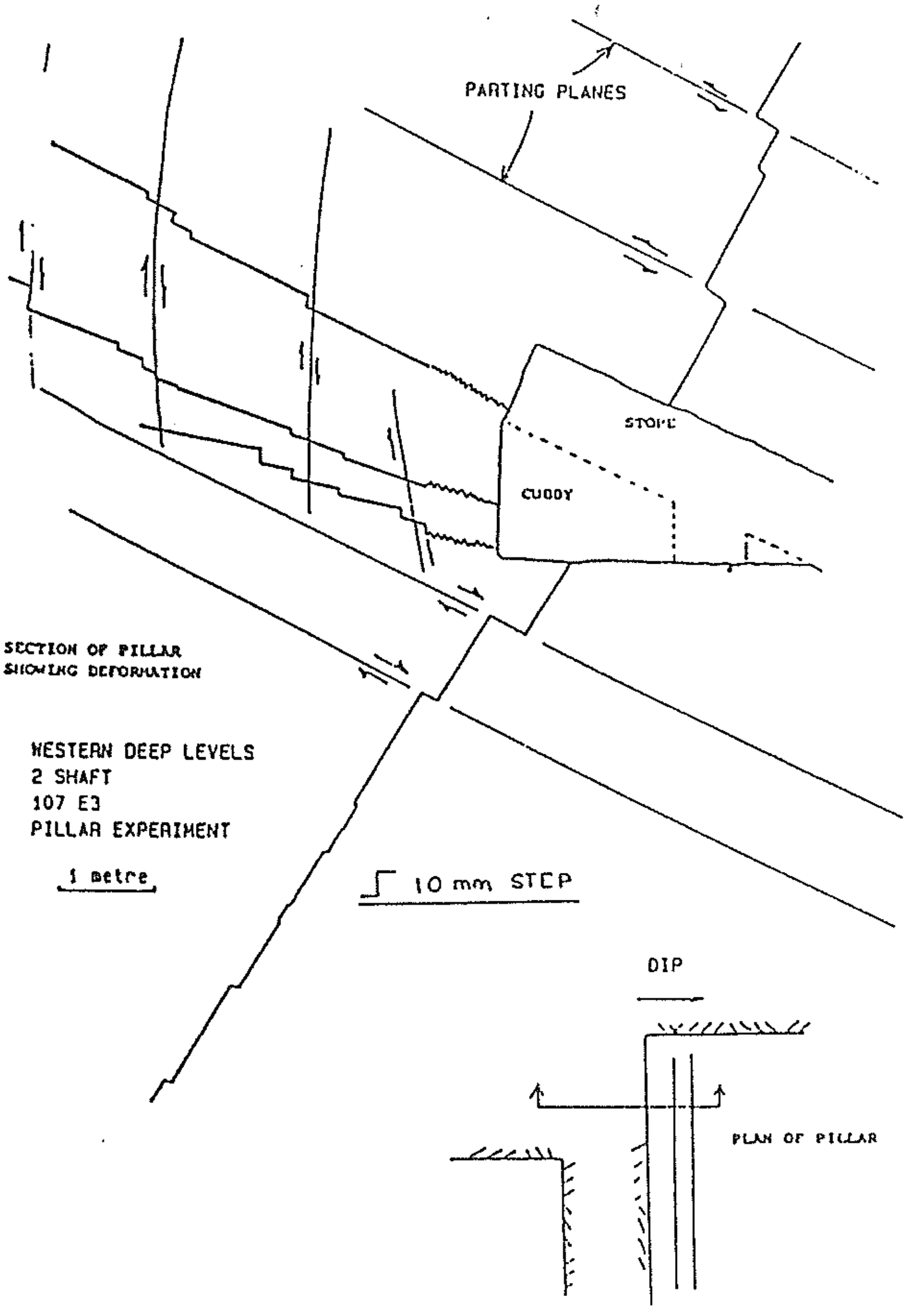


Figure 11 DISPLACEMENTS (STEPS) MEASURED IN BOREHOLES ADJACENT TO A PILLAR (AFTER BRUMMER 1984)

that relative to the rock 4 m above the stope, the immediate stope hangingwall moved 25 mm toward the stoped area while the stope face advanced 20 m. As the boreholes were drilled about 20 m behind the stope face, it is probable that a similar amount of movement had already taken place prior to drilling, i.e. about 50 mm by the time the face had moved 40 m.

These movements have also been confirmed by check surveys in gullies adjacent to pillars (Appendix I). The movements could break or buckle the thin hangingwall-parallel beams and could also cause partially formed, hangingwall-parallel fractures to extend.

Investigation is also needed of the extent to which falls of hangingwall are initiated by the movements of rock caused by scrapers whose snatch blocks are attached to the hangingwall. On two occasions the writer has observed minor movements, culminating in a fall, while a scraper was operating.

Rockbursts, even minor ones, may initiate many of the falls.

5 DISCUSSION

It was clear from the investigation that intense hangingwall-parallel fracture formation over the wide advance headings was the major feature distinguishing the hangingwall of gullies adjacent to pillars from hangingwall elsewhere in the stopes. Joints and bedding planes are likely to be as prevalent elsewhere in the stopes as over gullies. It is through their interaction with the hangingwall-parallel fractures that they have a more deleterious effect on gully hangingwalls than on the stopes generally. They cannot be removed but they should be taken into account when trying to overcome the problem.

Control of falls of hangingwall over gullies by the reduction of hangingwall-parallel fracturing over the gullies can possibly be achieved by modification of stope layouts. The alternative to such fracture control might lie in better support systems.

5.1 Modification of Hangingwall Fracturing Over Gullies Adjacent to Stabilizing Pillars

The development of intense hangingwall-parallel fractures has been found to be related to the presence of a wide advance heading (Figure 12) and so the obvious approach to reducing such fracture development lies in modifying the stope geometry to dispense with these wide headings.

Three modifications of the geometry which could have the desired result are discussed.

5.1.1 Mining with no gully heading at all

This mining geometry (Figure 13) would create cleaning problems due to the lack of over-run for the scraper. An alternative scraper system might overcome the problem but would require technical development. Moreover, as a probable result of stress across the corner of the stope (A-B) some shallowly arched, hangingwall-parallel fractures also occur with this geometry. These were seen at the top of the 107-47 mini-longwall in the 107-47 E3 escape gully at Western Deep Levels, where several falls had occurred. Being at the top of a mini-longwall, this gully did not have an advance heading and therefore had a geometry analogous to that in Figure 13.

To carry a 15 m or wider down-dip gully-siding would remove the gully from beneath the shallow arch of hangingwall-parallel fractures and hence from the area in which falls are most likely to occur. Also, by moving the gully from beneath the hangingwall which is likely to be disturbed because it is subject to most of the dilatational movement from the pillar, the gully hangingwall would be less likely to fall. The acceptability of such a solution would depend on the success with which the attendant complexities of up-dip scraping and recovery of sweepings could be overcome.

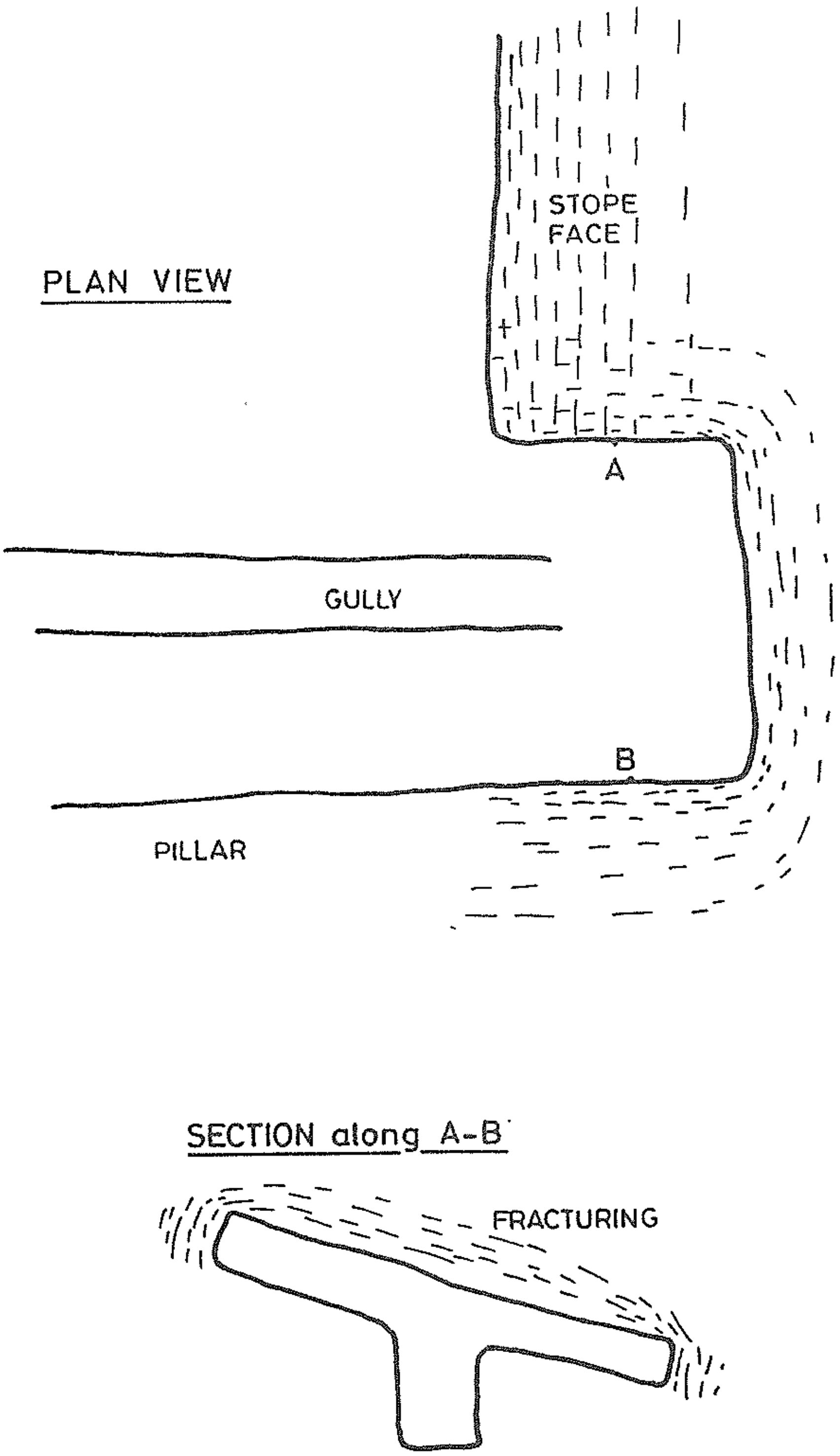
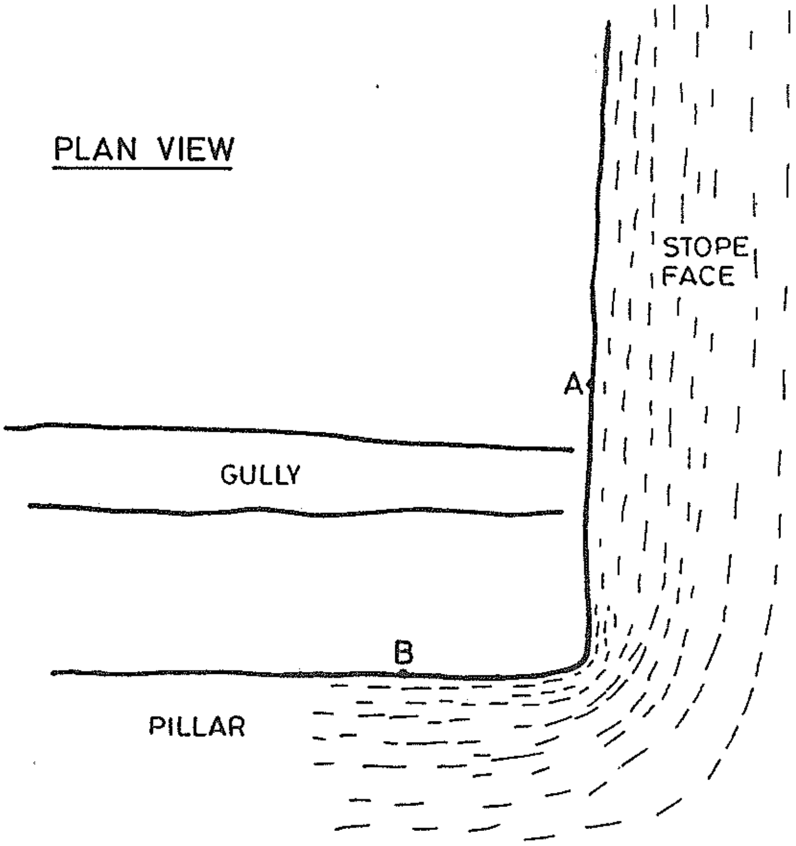


Figure 12 THE LAYOUT AND RESULTING FRACTURE PATTERN FOR MINING WITH A 10 m WIDE ADVANCED HEADING, 5-10 m AHEAD OF THE FACE



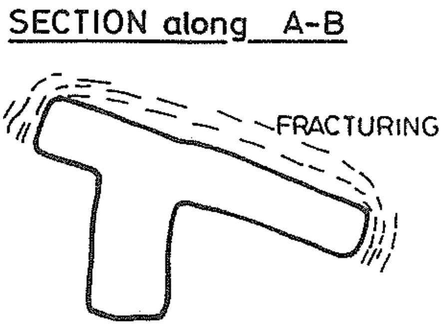


Figure 13 THE LAYOUT FOR MINING WITH NO ADVANCED GULLY HEADING AND THE RESULTANT FRACTURE PATTERN

5.1.2 Mining of the gully as an advance development end without any sidings ahead of the stope face

This technique (Figure 14) has been tested fairly successfully in the 104/38 W1 gully at Western Deep Levels. A down-dip siding was carried level with the stope face. The fracture pattern was modified as shown (Figures 14 and 15) and the minor falls that did occur fell to a stable arch only slightly wider than the gully (Figure 15). (In Figure 15, the clinorule is horizontal and the dip is to the right.) As a result of the height of the excavation at the gully face, it was possible to drill holes steeply into the relatively unfractured rock at the face and grout in shepherds-crook bars. This further stabilized the hangingwall. Stope-face-parallel fracture could be seen in the gully up to five or six metres ahead of the face, and it is probable that the rock within this distance of the face had been partially de-stressed. However it is advisable to keep the length of gully ahead of the face as short as possible.

The disadvantage of carrying a narrow, gully-wide development ahead of the face is that, because of the development of the gully-parallel fractures in the sidewalls of the heading which inflect at a level just below the stope footwall (point P on Figure 14), this footwall occasionally breaks away into the gully under the gully pack, thereby increasing the unsupported span across the gully. This problem has been previously recognized (Merson et al., 1976, Spengler, 1986).

By carrying the advance gully development with its hangingwall level with the footwall of the stope (Figure 16), the inflection (point P) of the gully-parallel fracturing could possibly be moved down sufficiently to stabilize the gully sidewall. This would have the added advantage that much of the arch of fractured gully hangingwall would be within the stope and would therefore be mined out.

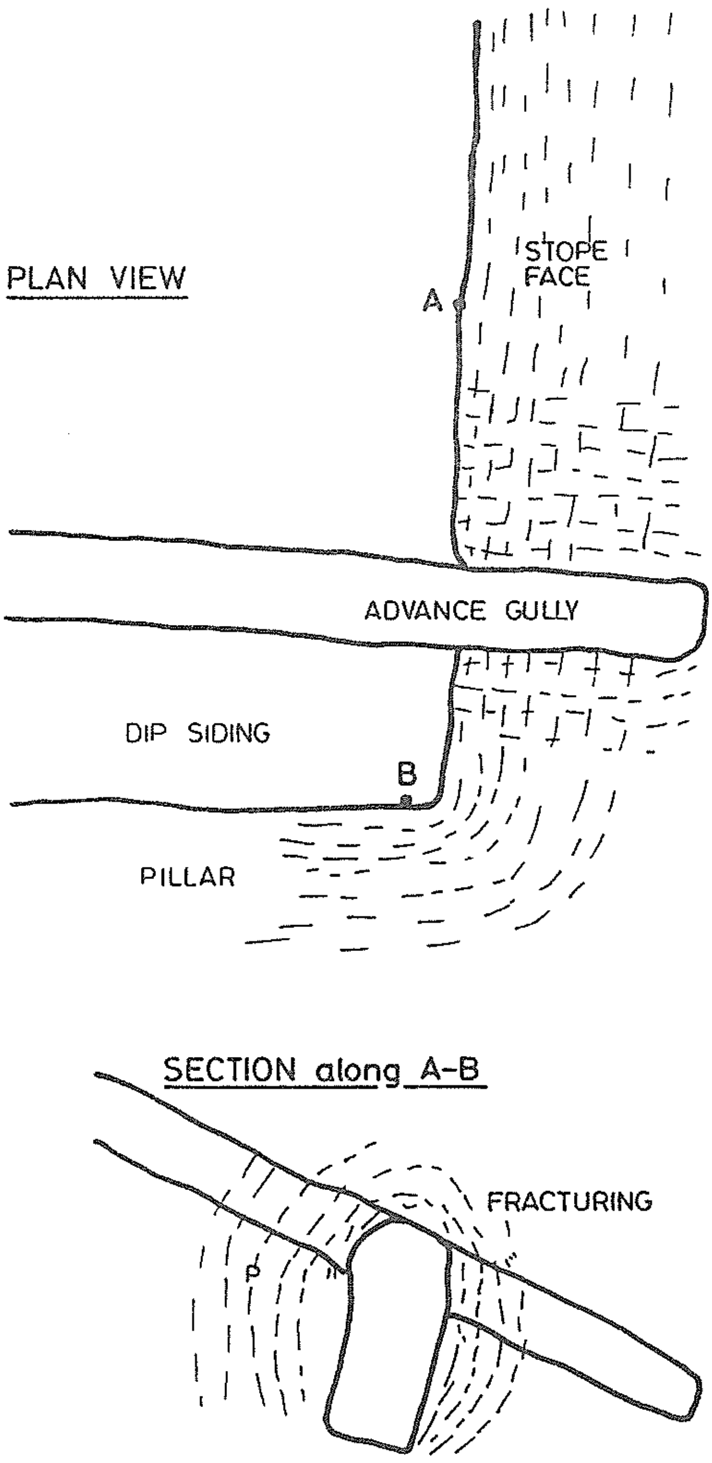


Figure 14 THE LAYOUT USED IN 104/38 W1 CARRYING ONLY THE GULLY AHEAD OF THE FACE AS AN ADVANCED HEADING AND THE RESULTANT FRACTURE PATTERN

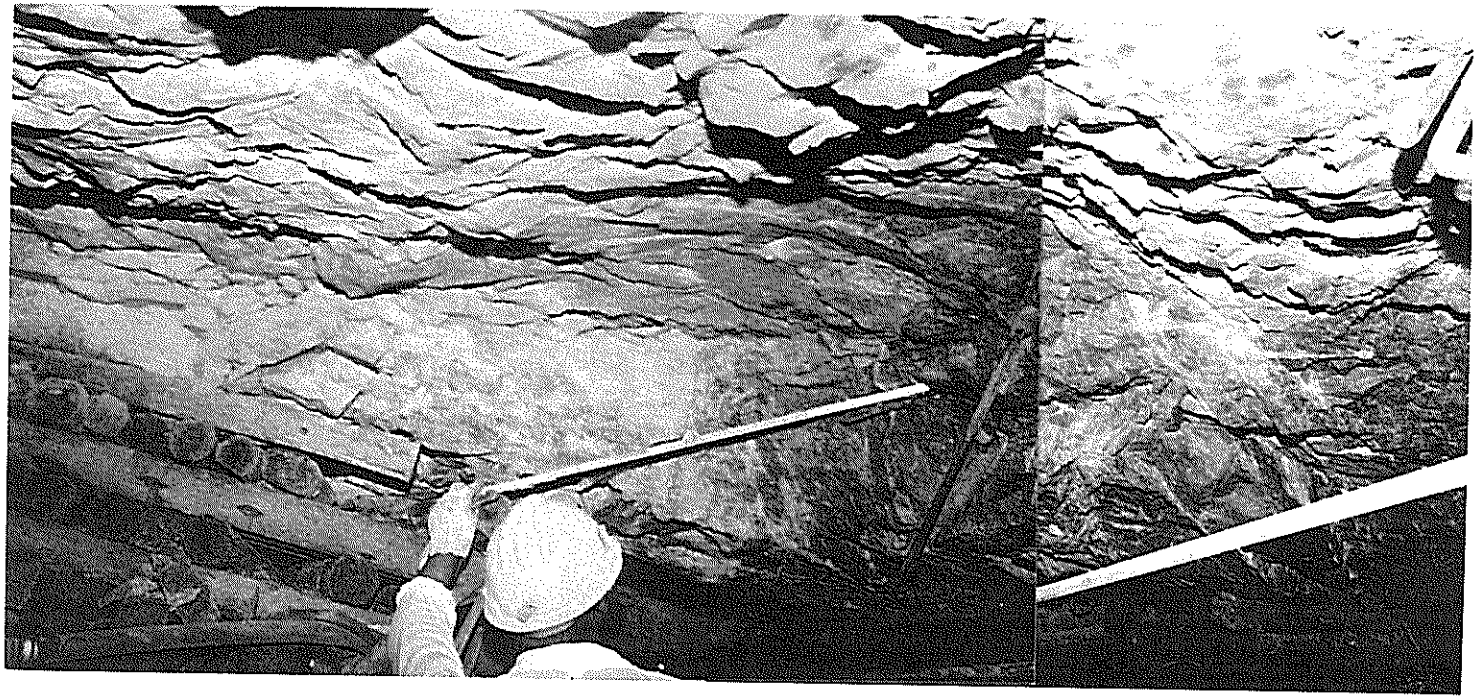
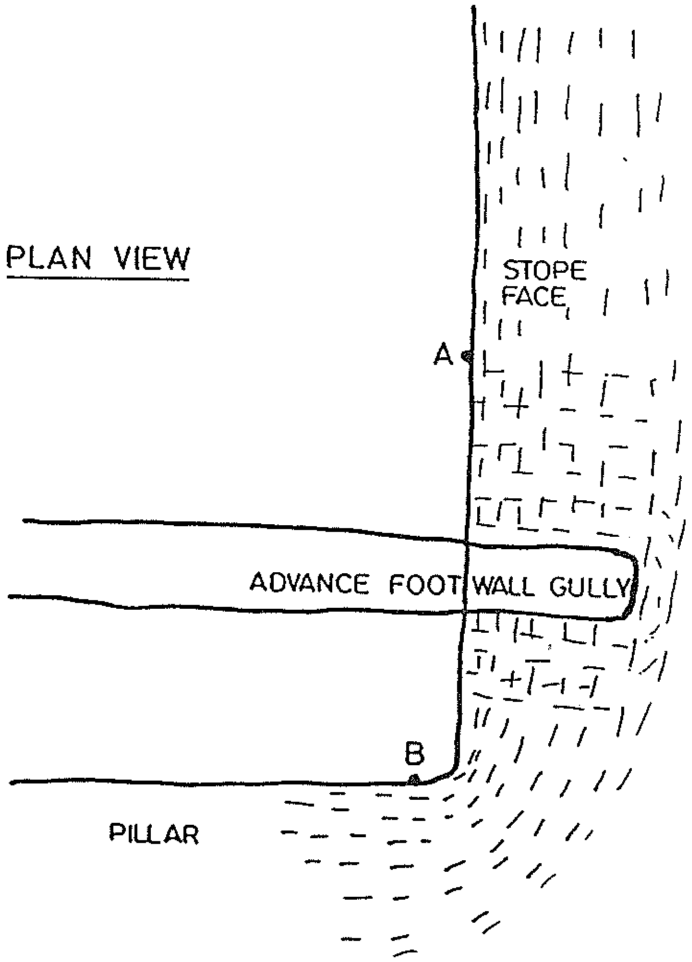


Figure 15 THE STABLE ARCH REMAINING AFTER A MINOR FALL OVER A GULLY MINED AS AN ADVANCED HEADING (104/38 W1 gully on Western Deep Levels)
Clinorule is horizontal and dip is to the right.



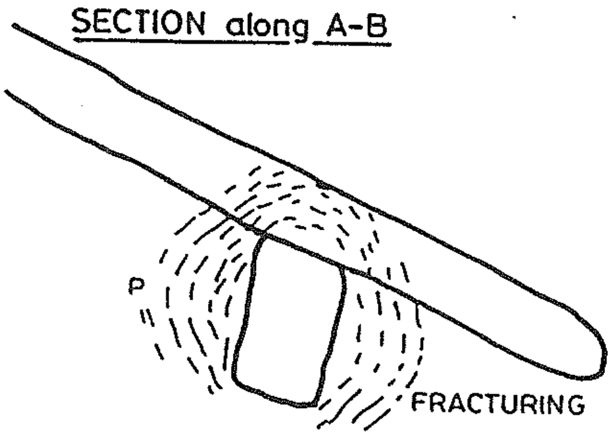


Figure 16 THE LIKELY FRACTURING AROUND A GULLY-WIDTH ADVANCE HEADING DEVELOPED IN THE FOOTWALL OF THE STOPE

5.1.3 Mining with a wide advance heading and with the panel above at an oblique underhand orientation

This mining configuration (Figure 17) is used on ERPM where hangingwall-parallel fracture is not developed. This absence of fracturing may not be due entirely to the presence of cross-bed parting planes in the hangingwall. MINSIM analysis shows that the horizontal stresses in the hangingwall are higher (by a factor of about 2 or 3) with this wide-advance-heading geometry than with the heading geometry used in the Carletonville area (Figure 12). However this analysis assumes elastic behaviour. The fracturing ahead of the underhand face may modify the stresses significantly. The matter needs further investigation before this configuration can be tried on Western Deep Levels or Blyvooruitzicht.

If, by modifying the stoping geometry as suggested, it is possible to eliminate the intensive development of hangingwall-parallel fractures, the only hangingwall-parallel detachment surfaces possible would be bedding-plane partings.

5.2 Modifications of Support Over Gullies

Where the gully hangingwall contains the three orientations of detachment surfaces, namely face-parallel, hangingwall-parallel and transverse, mentioned in Section 2, severe falls may take place. The close spacing of hangingwall-parallel detachment surfaces resulting from the present wide-heading mining geometry leads to severe falls of ground. To prevent or control these falls requires support with bearing surfaces extending over the gully. Three suggested support designs are sketched in Figures 18a to 18e.

The aim of all these support systems is to physically support as large an area over the gully as possible. In addition, support effectiveness might be improved by increasing the rockmass coherence through the use of grouted tendons or split sets. However, to be effective, tendon installation would need to be

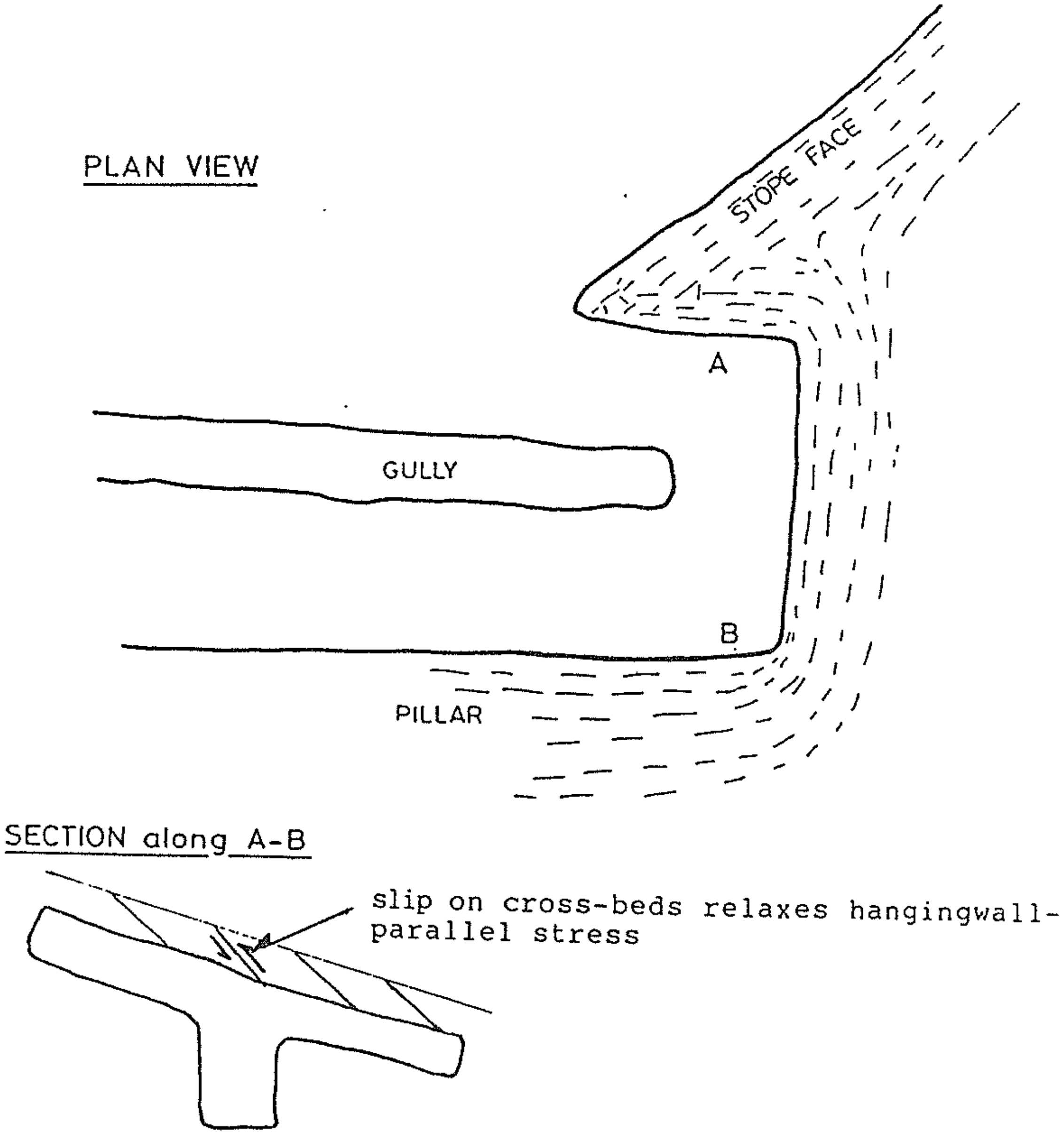


Figure 17 THE CONFIGURATION OF A WIDE ADVANCED HEADING AND A STRONGLY UNDERHAND FACE AS USED AT ERPM

Advantages	Disadvantages
1. Support across whole gully	1. Cost (moderate)
2. Bisteel strips cross face-parallel hangingwall beams of rock	2. If gully very full of rock scraper might snag on bisteel
3. Skeleton packs with top layer completely timbered will prevent falls between packs from extending into gully	

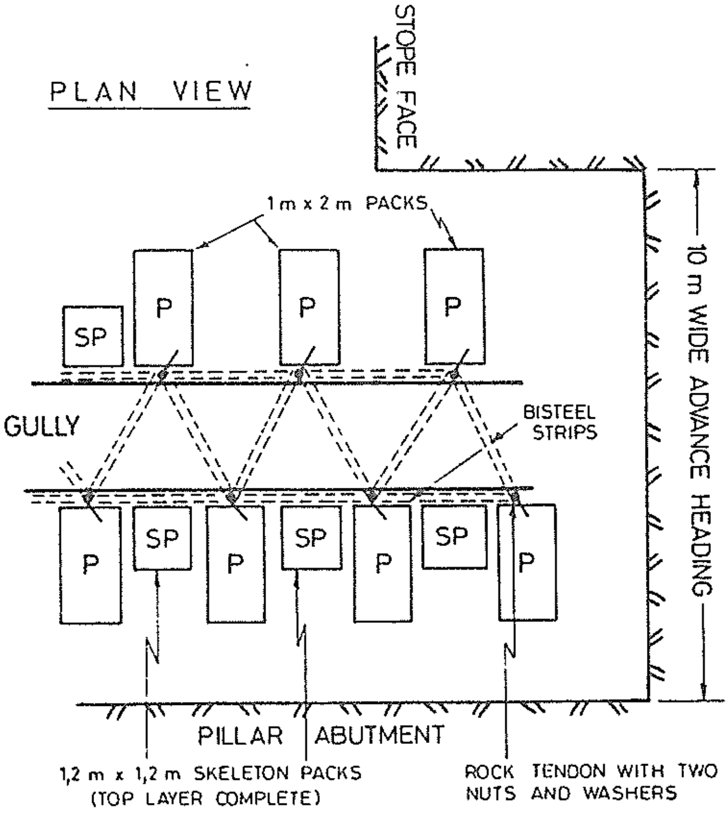


Figure 18a <u>PACKS ALONG SIDES OF GULLY + GROUTED REINFORCING BAR WITH THREAD. BISTEEL STRIPS IN TRIANGULAR CONFIGURATION. SKELETON PACKS BETWEEN STANDARD PACKS HAVE COMPLETELY TIMBERED TOP LAYER</u>

Figures 18a to 18e <u>SUGGESTED SUPPORT DESIGNS WHICH MIGHT BE USED TO REDUCE FALLS OF GROUND OVER GULLIES</u>

Advantages

1. Support across full width of gully
2. Pipe sticks will not crush nor be likely to bend till late in pack deformation
3. Pipe sheathing timber will reduce likelihood of fire due to scraper rope
4. Skeleton packs will prevent falls between packs extending into gully

Disadvantages

1. Cost of pipe sticks
2. Pipe sticks to not cross face-parallel rock beams
3. If gully very full scraper may snag on pipe sticks especially after stope closure

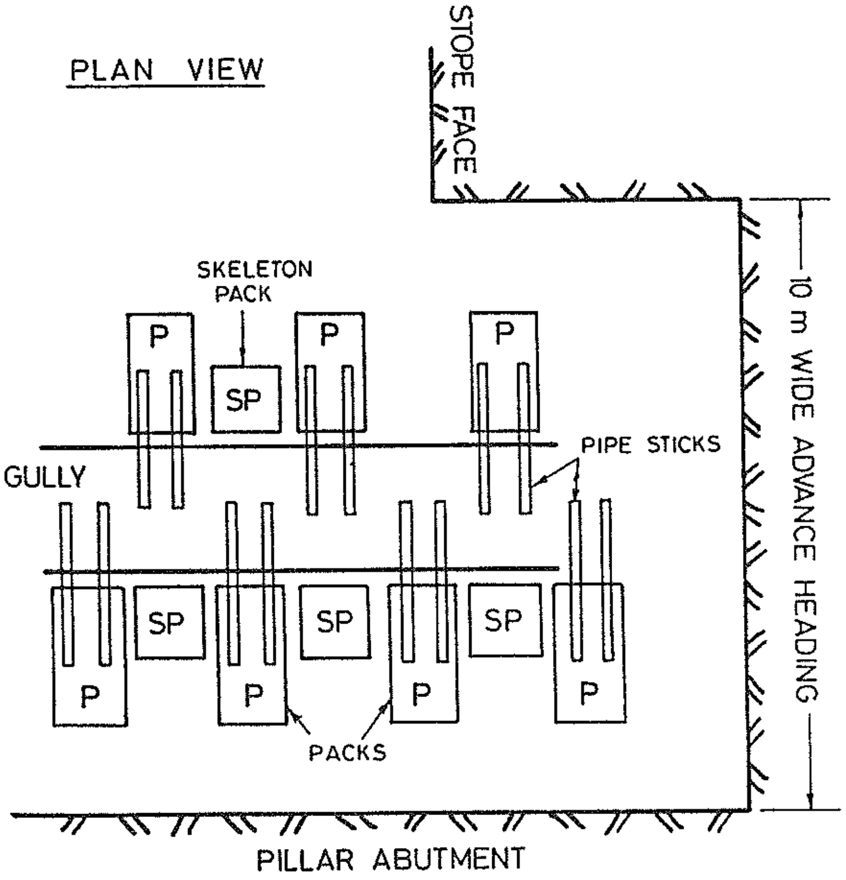


Figure 18b PIPE STICKS, BUILT INTO TOP LAYER OF ELONGATE PACKS, EXTEND OUT OVER GULLY. SKELETON PACKS BETWEEN STANDARD PACKS HAVE COMPLETELY TIMBERED TOP LAYER

Advantages

1. Support along middle of gully hangingwall
2. Cable crosses face-parallel rock beams
3. High tensioning force makes hangingwall into an effective pre-stressed beam
4. Cable is parallel with scraper path, thereby reducing chance of snagging by scraper

Disadvantages

1. Cable does not present very strong initial resistance to downward movement of hangingwall

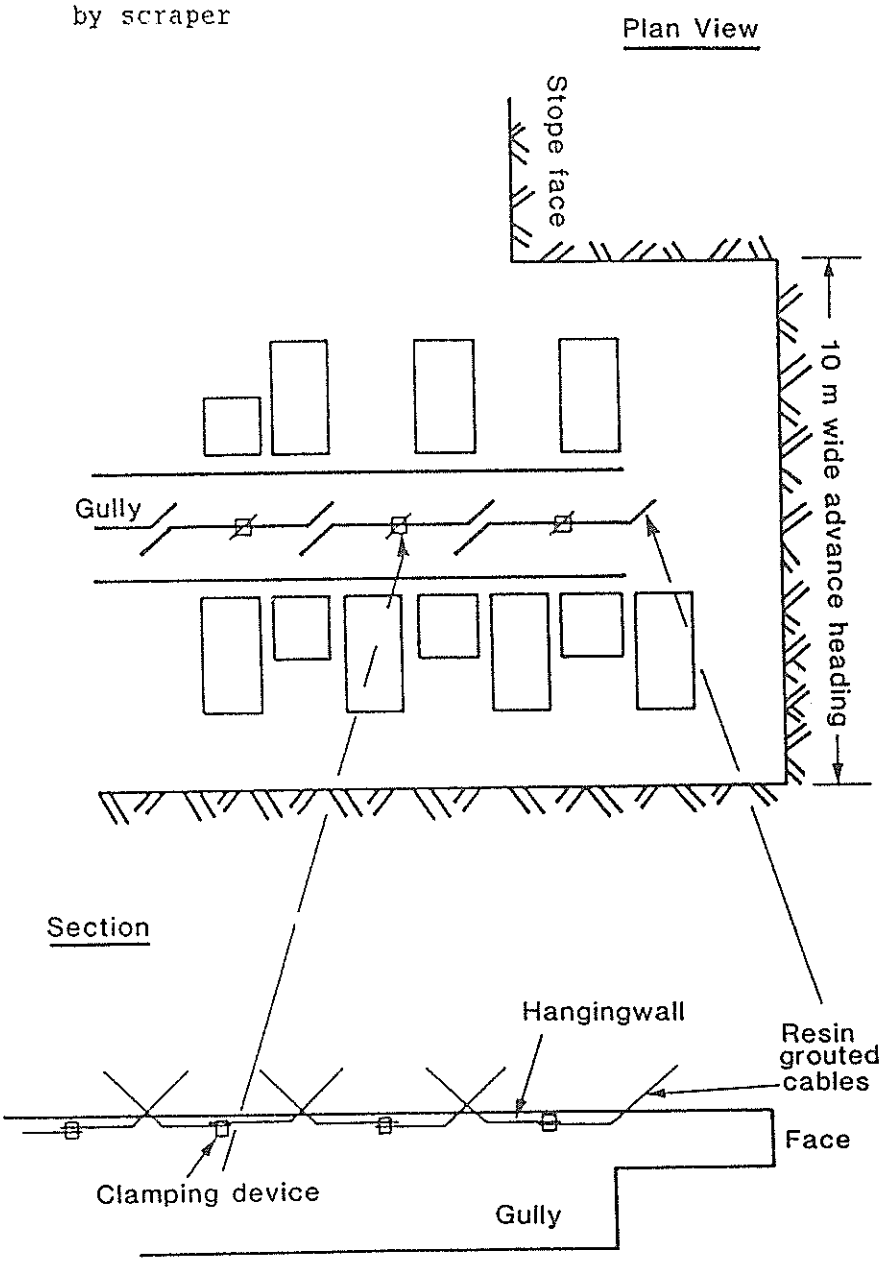


Figure 18c RESIN GROUTED CABLES TENSIONED TO 15 TONS AND CLAMPED. SKELETON PACKS WITH COMPLETELY TIMBERED TOP LAYER BETWEEN STANDARD PACKS

As in "Practical rock mechanics for gold mining" page 37 section 2.

Advantages	Disadvantages
1. Support across whole gully	1. High cost of steel beam
2. No fire hazard due to scraper cable contact with timber	2. Scraper may snag steel beam if gully very full, especially after stope closure

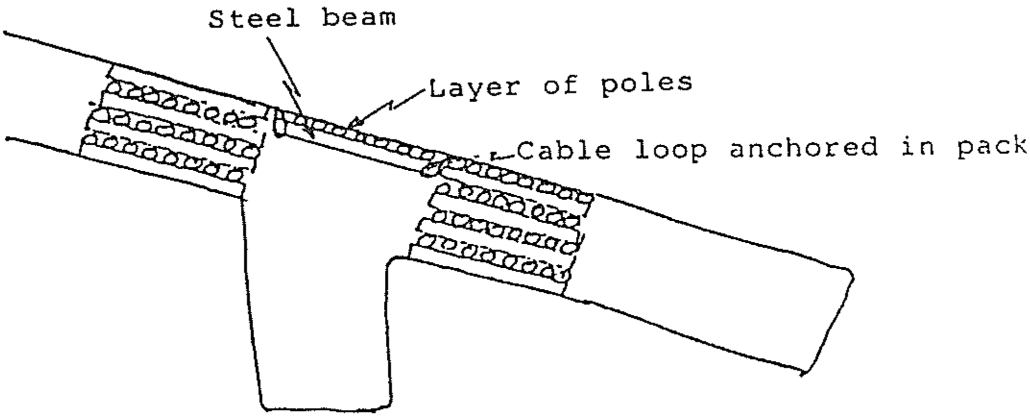


Figure 18d CABLE LOOPS ANCHORED INTO PACK SUPPORT TWO STEEL BEAMS ON WHICH A LAYER OF POLES IS PLACED

Advantages

1. Could support badly fragmented hangingwall
2. No fire hazard

Disadvantages

1. Scraper could snag mesh and beams if gully very full especially after stope closure
2. High cost of steel beam and mesh

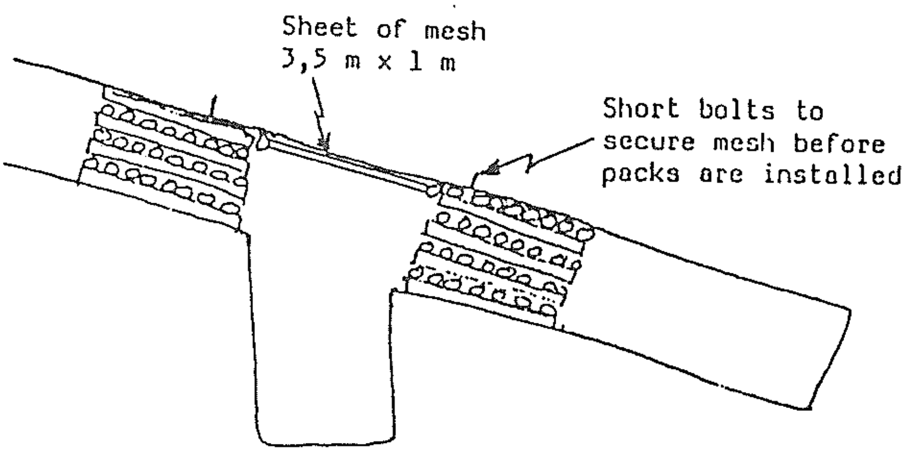


Figure 18e WIRE MESH STRIPS BRIDGING BETWEEN PACKS (POSSIBLY ASSISTED BY DIAGONAL STEEL BEAM SUSPENDED FROM CABLE LOOPS AT OPPOSITE CORNERS OF PACKS, SO AS TO CROSS GREATEST NUMBER OF FACE-PARALLEL HANGINGWALL SLABS)

done at the heading face. The narrow stoping width (1 m) would make this difficult.

Pack instability on the down-dip side of gullies can also pose a problem. It has been noted that it is mostly these packs which have to be rebuilt after falls along the gully. This pack instability may be due to rock movement away from the pillar, such as that discussed in Section 4. This matter needs further investigation. The performance of gullyside packs is the subject of a current research project.

Should a fall of hangingwall occur over the gully, the movement of the hangingwall away from the stabilizing pillar will be easier and may render the pack on the pillar side of the gully unstable, and easily displaced by even minor seismic events. A system is thus necessary for staying the down-dip gully packs against an up-dip movement.

In contrast, packs on the up-dip side of gullies appear relatively stable. Even though the hangingwall has been fragmented, the extension of falls over the gully in an up-dip direction has occurred predominantly by fall between the packs, with the packs supporting the rock directly above them.

The fragmentation of the hangingwall can also result in falls either in the heading or close to the stope face. After these falls have taken place, the absence of adequate horizontal force across face-parallel detachment surfaces will allow forward extension of the falls to take place more readily. Hydraulic props with headboards could re-establish the frictional forces across detachment surfaces and thereby facilitate the reinstatement of a stable hangingwall.

6 CONCLUSIONS AND PROPOSALS

Excessive development of hangingwall-parallel fractures is the one form of detachment surface which contributes to hangingwall instability and whose incidence can be reduced. In this regard it is proposed that

(i) several gully headings adjacent to stabilizing pillars should be modified along the lines described above and illustrated in Figures 14 and 16, to confirm the influence of gully-width headings in reducing hangingwall-parallel fracture development; these gullies should not protrude more than is necessary (3 m) ahead of the stope face.

(ii) at least one of these gullies should be mined with the advanced gully development beneath the plane of the stope, as shown in Figure 16;

(iii) if possible, in both the full height advance-gully stope and the footwall-height advance-gully stope, a four or five metre long dip gully should be developed. This dip gully should be excavated up-dip, behind the swept area of the stope, to expose the footwall fracture-geometry and thus enable the likely stability of the footwall beneath up-dip gully-side packs to be assessed;

(iv) more gullies on ERPM be examined to determine whether factors other than hangingwall cross-bedding are causing the stability of the gullies, and, in particular, whether the heading geometry is, in effect, reducing hangingwallparallel fracturing;

(v) the co-operation of the mines, in which these studies were undertaken, should be sought in experimenting with some of the designs suggested to support areas of closely fractured or bedded and jointed hangingwall. The reduction of hangingwall-parallel fractures by the mining geometry changes discussed above will still have left unresolved the problem of control of closely-bedded hangingwalls. These do not occur frequently but when they do they can be a serious problem.

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APPENDIX I

MOVEMENTS OF THE HANGINGWALL REVEALED BY CHECK-SURVEYS

A useful source of information regarding the movement of the hangingwall has been a check-survey of the 47 longwall east, by the Western Deep Levels survey department. This check-survey, which was initiated from the main shaft, showed that the pegs had displaced appreciably, relative to the anticipated positions. As this was the first check-survey conducted since stoping commenced on the 41 line, the displacements were attributed to the cumulative effect of displacements during the 1 000 m stope advance prior to pillar introduction and the displacements during the 500 m stope advance after the introduction of pillars.

Movement prior to the pillar introduction would have been partly due to stope closure perpendicular to the stope plane resulting in the up-dip displacement of a peg (Figure I.1). This movement would be about 190 mm for a 500 mm closure movement of a 1 m wide stope which was inclined at 20° (the footwall should rise 500 mm giving total closure). This movement is likely to be partially offset by down-dip ride of the hangingwall.

The overall effect would be that pegs would actually be further up-dip than they were thought to be. The reason for this is that at the time of surveying, the station peg (Figure I.2) would have moved considerably up-dip relative to the installed position, due to closure. However, the back-site peg, would have moved very little since it was used as the station peg, because most of the closure would have taken place within 25 m of the face. The result would be that whereas the surveyor would assume the back-site line to be BA, it would in fact be CA (Figure I.2). The foresite line would therefore be CE instead of BD which the surveyor believed it to be; i.e. the peg would be calculated to have coordinates of the point D but would actually have the coordinates of E. This process is repeated as the gully is extended, moving the actual position of each successive peg progressively further up-dip of its calculated position.

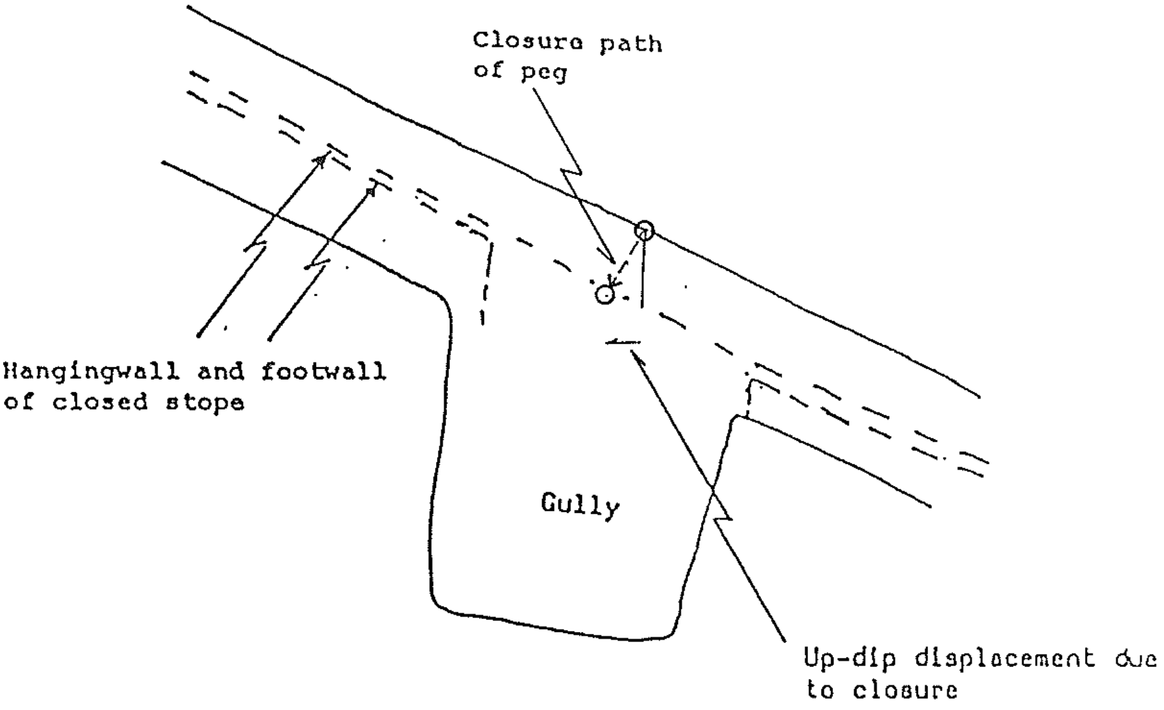


Figure I.1 MOVEMENT OF PEG DUE TO STOPE CLOSURE
Closure perpendicular to a dipping stope will result in the up-dip displacement of a survey peg

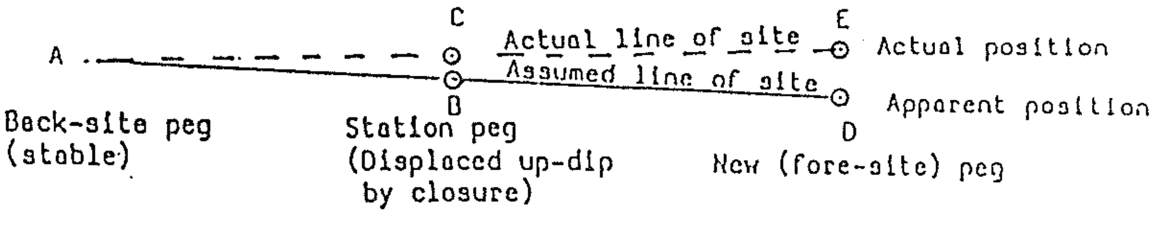


Figure I.2 SURVEY ERROR DUE TO PEG MOVEMENT
Lateral movement of a peg, between the time that it is installed and the time that it is used for surveying the next peg, leads to erroneous con-ordinates being calculated for the latter peg.

Past check-surveys, conducted elsewhere on the mine and well before the introduction of pillars, have shown that the corrections indicated by these surveys are of similar magnitude and direction through a whole series of adjacent panels and are generally up-dip as expected. It is reasonable to assume that, at the stage when pillars were introduced, the required corrections, i.e. cumulative errors, in the top and bottom gullies of a mini-longwall would have been about the same, say x_1 metres.

After the introduction of the pillars closure in the gullies adjacent to them would be much less than previously. However, for a given advance closure could be expected to be similar on either side of a pillar and thus similar at the top and bottom of each mini-longwall. The result in each case, would be an up-dip correction of say x_2 metres. The total up-dip displacement would be $x = (x_1 + x_2)$ m.

Subsequent to the introduction of the pillars, dilatation of hangingwall away from the pillars would have resulted in a down-dip displacement over the top gully and an up-dip displacement of the hangingwall over the bottom gully. If, as with the displacement due to closure, the back-site peg stabilizes so that it moves less than the station peg, there will be an error in the fore-site direction. This error would, in effect, cause the new peg above the pillar to be further up-dip than calculated from the survey, while the pegs below the pillar would be further down-dip.

If the actual hangingwall displacements due to dilatation are assumed to be the same distance on either side of the pillar, say y metres, and the average strike spacing between pegs is 20 m, the cumulative displacement along the 500 m of pillar length will be

$$500/20\ y = 25\ y \text{ m}$$

The total displacement (corrections) 'd' necessary on the up-dip side of the pillar will be (considering up-dip displacement as positive)

$$d = x + 25\ y \text{ m}$$

while that on the down-dip side will be

$d = x - 25\ y$ m

On the 106/47 East mini-longwall the total correction for the E1 gully was 3,5 m while for the E3 escape gully no correction was necessary. Thus

$$x + 25\ y = 3{,}5 \text{ m}$$
and $$x - 25\ y = 0 \text{ m}$$

Solving for x

$$2\ x = 3{,}5 \text{ m}$$
and $$x = 1{,}75 \text{ m}$$

from which

$$25\ y = 1{,}75 \text{ m}$$
and $$y = 0{,}07 \text{ m}$$

On the 107/47 East mini-longwall the relevant equations are

$$x + 25\ y = 4{,}0 \text{ m}$$
$$x - 25\ y = -0{,}5 \text{ m}$$

from which once again

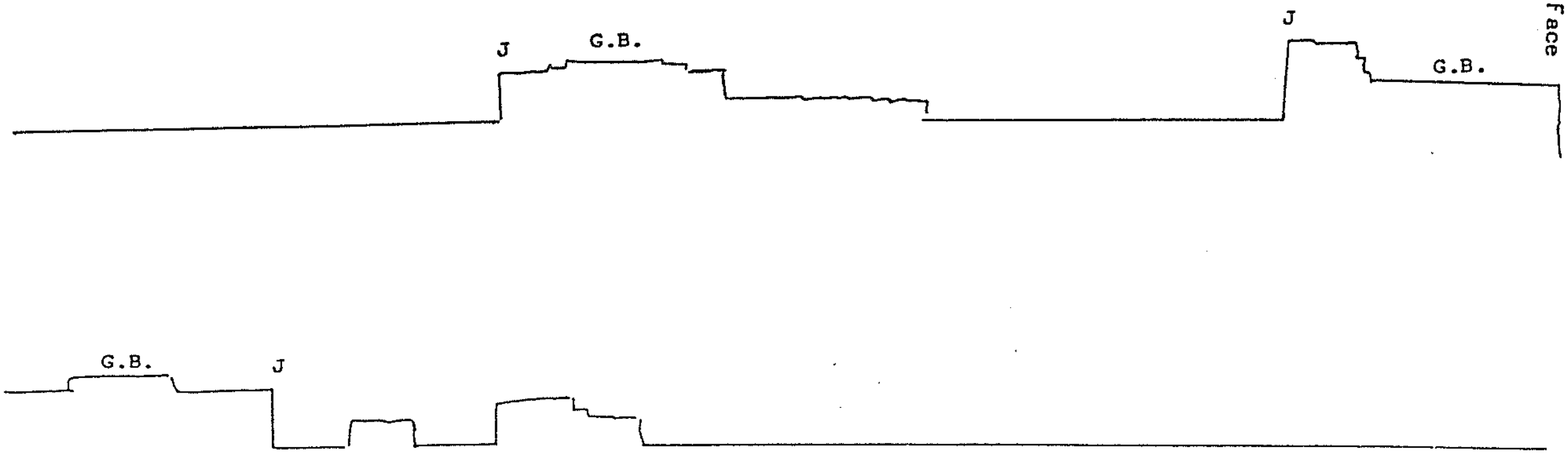
$x = 1{,}75$ m and
$y = 0{,}07$ m

The step-meter displacement measurements described in Section 4, Figure 11 indicated similar displacements of 0,05 m during a face advance of 40 m

APPENDIX II

HANGINGWALL PROFILES ALONG STRIKE GULLIES ADJACENT TO PILLARS

The incidence and vertical extent of falls relative to the original (mined) planar hangingwall surface is shown. In these profiles the bounding surfaces of falls are fractures unless they are signified as joints (J) or the Green Bar shale (GB).



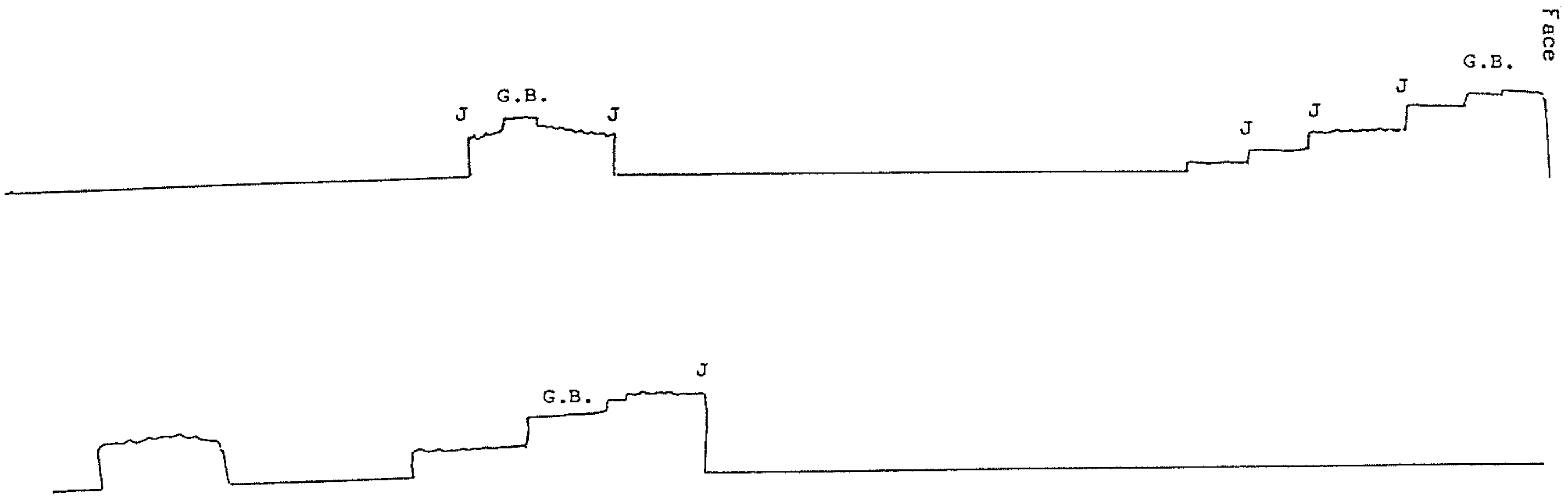
106/47 E1 gully, Western Deep Levels

Scale 1 : 200

Legend:

J = Joint
G.B. = Green Bar

Figure II.1 PROFILE ALONG 106/47 E1 GULLY, WESTERN DEEP LEVELS



107/47 E1 gully, Western Deep Levels

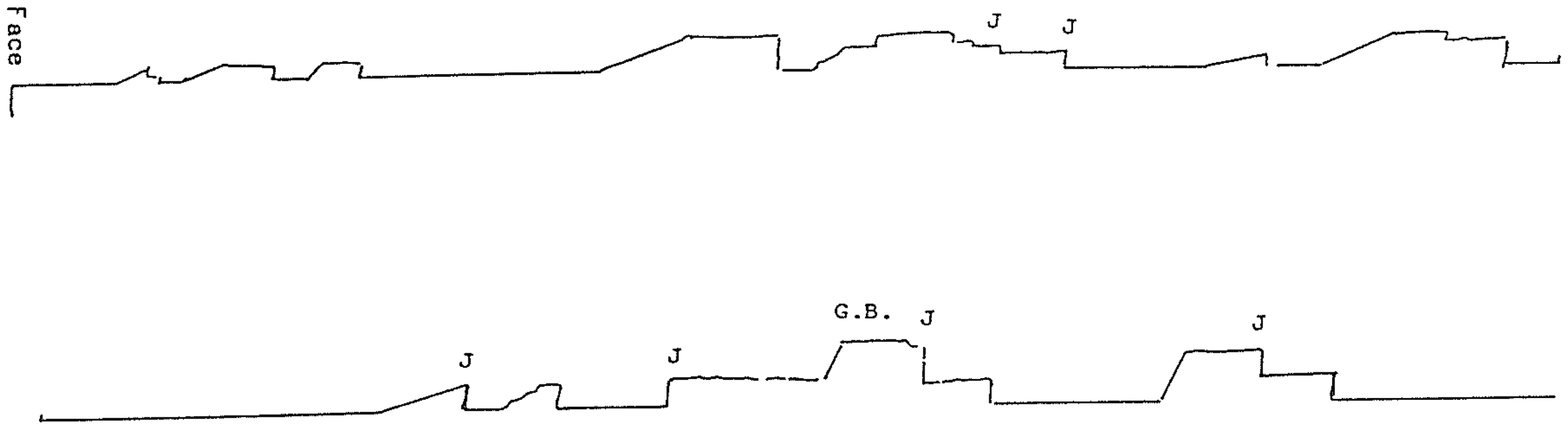
Scale 1 : 200

Legend:

J = Joint

G.B. = Green Bar

Figure II.2 <u>PROFILE ALONG 107/47 E1 GULLY, WESTERN DEEP LEVELS</u>



28 W gully, B4 L.W., Blyvooruitzicht

Scale 1 : 200

Legend:
J = Joint
G.B. = Green Bar

Figure II.3 <u>PROFILE ALONG 28 W GULLY, B4 LW. BLYVOORUITZICHT</u>