Proceedings, 12th CMMI Congress. H.W. Glen (editor).
Johannesburg, S. Afr. Inst. Min. Metall. (or Geol. Soc. S. Afr.), 1982.

The design and introduction of stabilizing pillars at Blyvooruitzicht Gold Mining Company Limited

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Synopsis

For the entire deeper part of its lease area, Blyvooruitzicht has been committed to conscientious adherence to longwall mining as its principal measure against the problem of rockbursts. Because of certain practical production considerations and the occurrence of a number of serious rockburst indicents, it became necessary to adopt an alternative stoping strategy.

This paper briefly examines the history of pillars in Witwatersrand gold mining as a background to the introduction of longwall stoping four decades ago and its recent modification on East Rand Proprietary Mines Limited to a system of longwalling with stabilizing pillars.

The justification of the decision to leave stabilizing pillars on Blyvooruitzicht is discussed, and the analytical work on the electrical analogue that preceded the change is briefly outlined.

Details are given of a seismic network that was introduced to monitor the effectiveness of the system and to provide some insight into the more fundamental aspects of the phenomenon of rockburst. Although insufficient time has passed to allow a definitive appraisal, there are preliminary indications that the rockburst problem has become less severe and that the stope productivity has increased.

Introduction

Blyvooruitzicht Gold Mining Company Limited is the oldest of the group of mines in the area that was once termed the West Wits Line and is now better known as the Carletonville district.

Since production started in 1942 it has exploited some 60 per cent of the Carbon Leader Reef, which has so far proved to be the only payable horizon, some 2184 inclined hectares in extent, that underlies the lease area. With the present rate of mining and the current gold price, the remainder of the mine's life is limited.

Until 1966 stoping was restricted to the upper half of the mine above 16 level at 1920 m below surface. Above this moderate depth, the mine was initially laid out for scattered stoping from raises at 200 m intervals on strike. The many remnants that inevitably resulted from this system (Fig. 1) were generally extracted with relatively little trouble, except where they were complicated by geological features.

Although not as common as on the deep mines of the central Witwatersrand, the problem of rockbursts was sufficiently real to have been among the foremost considerations in the layout of the deeper half of the mine. At that time, the best strategy for minimizing rockbursts was the adoption of a longwall layout. Thus, the 1400 m of dip length of Carbon Leader below 16 level was exposed by a series of centre raises above each of four inclined shafts sited deep in the footwall. Each raise was ledged out more or less simultaneously over its entire length to establish breast longwalls over 1 km long (Fig. 1). The use of diagonal scraper gullies, instead of strike gullies, made it possible for the 45 m long stope faces to be cleaned without the need to advance the gully beyond the line of the faces or to have the bottom panel leading. The result was that the longwalls were longer and straighter than longwalls anywhere else before or since.

This system served fairly well for the most part but on rare occasions, and fortunately usually during blasting time, severe rockbursts would cause simultaneous damage to the greater part of a longwall. Notable examples occurred along the B3 longwalls in April 1971 and November 1971, while about one-third of B1W longwall was damaged in August 1972.

From the outset it was realised that the rockburst problem would become very grave if the longwalls approached each other in parallel fashion to form long, slender remnants. In principle, this dangerous geometry could be avoided by changing the general longwall direction. An underhand peaked longwall with final remnants taken out on 30 level, or an

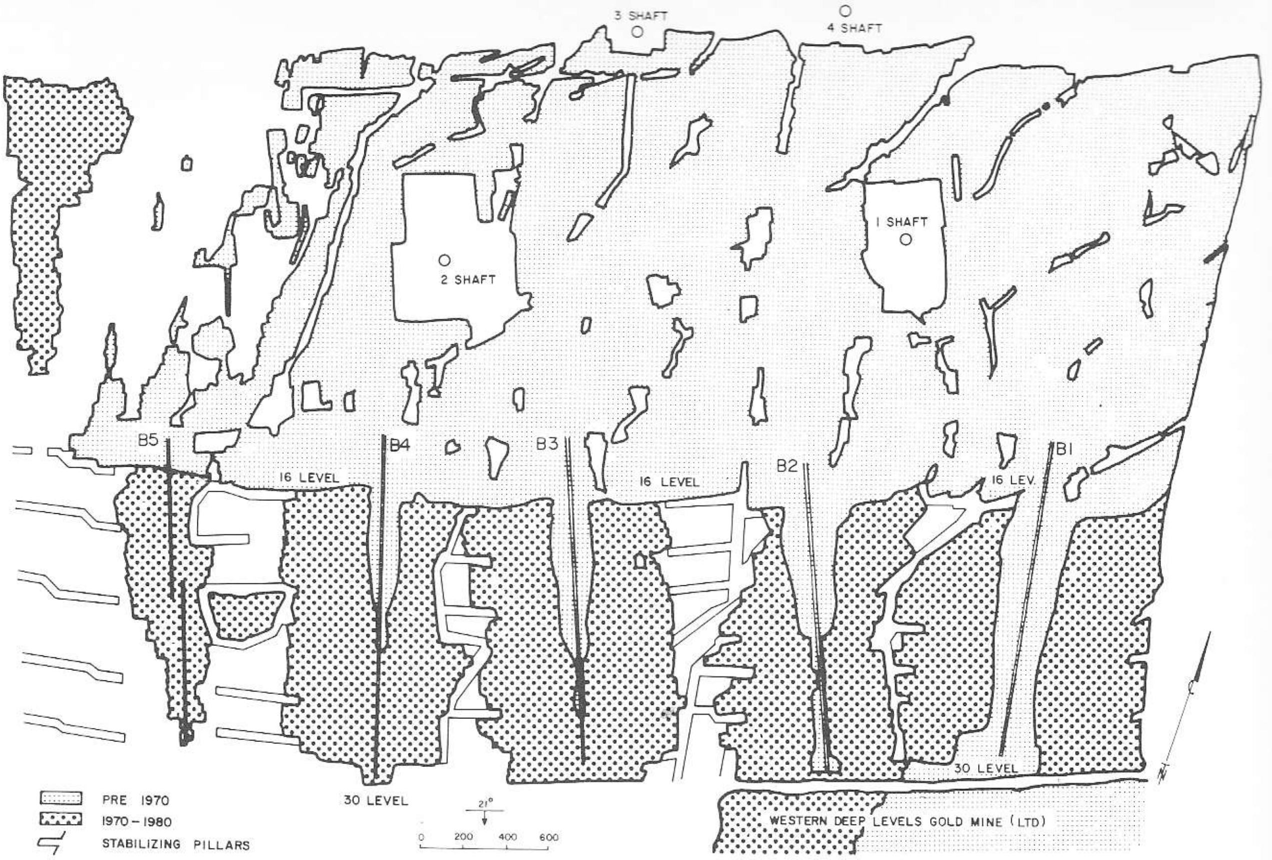

Fig. 1—Plan of Blyvooruitzicht, showing remnants above 16 level, and longwalls and stabilizing pillars below 16 level

overhand stepped longwall with the final remnants being formed just below 16 level were the two possible alternatives.

The existence of a neighbouring mine below the southern boundary and the argument that the stresses would be lower at the shallower depths near 16 level indicated that the latter alternative would be preferable. However, during the vital period of the midlife of the longwalls around 1974, it was found virtually impossible, in the presence of the dominant dyke system then encountered, to exercise the necessary control on the rate of advance along the length of the longwalls. It was not possible to increase face advance significantly along the lower portions of the longwalls, and production demands precluded the slowing down of the upper faces. A state of virtual deadlock existed between the long-term requirement for drastic change in the total mine layout and the short-term demands of maintaining gold production when, at any given time, a significant proportion of the total face-length was stoping in dyke.

Mining in dykes is always more difficult than stoping in ore and, in addition, the rockburst hazard is magnified many times, particularly when a stope face is parallel to the dyke contact. After three particularly serious rockbursts in dyke, which occurred in August and September 1977, the decision was taken to implement the major steps necessary to break out of the dead-locked situation.

This paper discusses the rationale for the new layout of stabilizing pillars that was then adopted for the entire mine, outlines the analysis that determined the choice of pillar dimensions, and describes the seismic research system that will monitor their effectiveness.

Philosophy of Pillar Mining

Until recently it was generally believed that on no account should reef pillars be left in deep-level stopes and that, wherever possible, dykes and fault losses should be stoped through. In order to explain this belief and to illustrate the effect that it has had on mine design, it is necessary to give a brief review of the history of pillars in the Witwatersrand gold mines.

Apart from timber props for local support, pillars were the most obvious form of support for the stoping of the outcrops and shallow areas of the tabular conglomerates of the central Rand. In view of the low rate of convergence at shallow depths, these support methods were also the most suitable.

As the depth of mining increased to a few hundred metres by the first decade of this century, it became apparent that isolated reef pillars could fail. Because of the strong and brittle nature of the rock, the pillar failures were often violent. In 1908 the State-appointed Ophirton Earth Tremors Committee concluded that the 'shattering of support pillars' was the cause of the tremors that were then becoming a problem. This conclusion was endorsed in 1915 by the Witwatersrand Rockburst Committee, who found that 'the sudden crushing of pillars' was the major cause of rockbursts. It was specifically recommended that the use of pillars should be eliminated and substantial artificial support used instead.

The very comprehensive conclusions of the 1924 Witwatersrand Rockburst Committee included the unequivocal recommendation that 'at depths exceeding 1 500 feet the formation of pillars and remnants of reef should be avoided wherever practicable' (paragraph 65).

While recommending that, where protective pillars were left around shafts, such pillars should be large, the 1964 Rockburst Committee also stated clearly that pillar support could not be recommended in areas prone to rockbursts.

In a decisive attempt to eliminate remnant pillars that were the cause of many rockbursts, longwalling, already tentatively advocated in the 1924 Committee recommendation, was introduced on East Rand Proprietary Mines Limited (E.R.P.M.)[1] in 1942. The initial success of the method led to its widespread adoption on other deep mines of the central Rand, and it became the accepted technique for deep-level mining. In addition to the main purpose of reducing the number of remnants, a basic argument for longwalling was that the strict alignment of straight stope faces eliminated local stress concentrations that caused rockbursts.

In terms of this requirement of straightness, the longwalls on E.R.P.M. up to about 1960 were very well controlled (Fig. 2). Those that were developed on Blyvooruitzicht Gold Mining Company Limited from 1968 to 1972 were even closer to the ideal configuration (Fig. 1). While it appeared that the incidence of slight and medium rockbursts was reduced, occasional very large rockbursts affecting the greater part of a longwall still occurred on these two mines. One such event, which occurred on E.R.P.M. in February 1966, damaged some 550 m of the Angelo longwall and caused an estimated production loss of 395 rock-drill shifts. On Blyvooruitzicht, rockbursts caused severe damage along 460 m of B3E longwall in April 1971 and along 790 m of B3W in November 1971. In August 1972, a length of 330 m of B1W longwall was severely damaged. Many other instances where lengths of 200 m and more of longwall face were affected have been recorded.

Introduction of Stabilizing Pillars

It was intuitively recognized by some perceptive mining engineers that large unmined areas of ground could reduce the stress concentration on stope faces in the vicinity. However, innovative thinking in the direction of exploiting these beneficial effects in a systematic way would have been inhibited by the

Fig. 2—Plan of E.R.P.M., showing the K section longwalls, and, on H Section, the stabilizing pillars below 68 level and the 1957 longwalls above 68 level

weight of the authoritative opinion and official recommendations already described. Another major factor against leaving pillars was naturally the considerable loss of revenue that resulted from deliberately leaving developed ore reserve.

Despite these contrary influences and with the object of limiting the span in the dip direction, the decision was taken in 1963, after a succession of serious rockbursts on E.R.P.M., to leave the tops of the Hercules East and West longwalls on 69 level as continuous strike pillars (Fig. 2).

Late in 1966, additional stabilizing pillars were left on 72 level after careful consideration of the energy-conservation arguments expressed by Cook *et al.*[2]. Essentially, Salamon (who is one of the authors) demonstrated the dramatic effect on the energy release rate of limiting the span in the direction perpendicular to the direction of face advance, and proposed the concept of partial extraction as a means of mitigating the rockburst hazard. This deliberate and major policy change was ratified by the company directors and was brought to the notice of the Government Mining Engineer early in 1970. The circumstances leading up to this adoption of a new strategy have already been described elsewhere[3].

It is very difficult to keep meaningful and reliable records of the consequences of such a capricious phenomenon as rockbursting. Consequently, it is not easy to prove the efficacy of any countermeasures adopted. However, some indication of the reduction in the severity of the rockburst hazard is provided by an examination of the casualty rates, which may not be entirely meaningful but are, at least, reliable data. The rates for the two most representative sections of E.R.P.M. sections H and K, which are shown in Fig. 2, are compared in Fig. 3.

Seismic activity is more reliably measured than rockburst incidence, and it has been shown[4] that the actual seismic energy radiated per unit area mined was reduced by 60 per cent in stoping areas protected by stabilizing zones. The reduction in events of magnitude 2,0 and larger was even greater and, since it is the larger seismic events that are usually responsible for the loss of life and production, it is obvious that morale and mining conditions were greatly improved.

Stabilizing Pillars at Blyvooruitzicht

The decision to adopt stabilizing pillars throughout the whole of Blyvooruitzicht was based to a large extent upon their success on the Hercules section and, to a lesser extent, the Angelo section at E.R.P.M. What was more important than the somewhat inadequate statistics in influencing the Blyvooruitzicht decision was the very real conviction on the part of the E.R.P.M. management and men that stabilizing pillars are of great benefit to production and safety.

In addition to the entirely theoretical argument, which is naturally equally applicable to both mines, the geological circumstances at Blyvooruitzicht appeared to provide a further justification for the change in total mine layout.

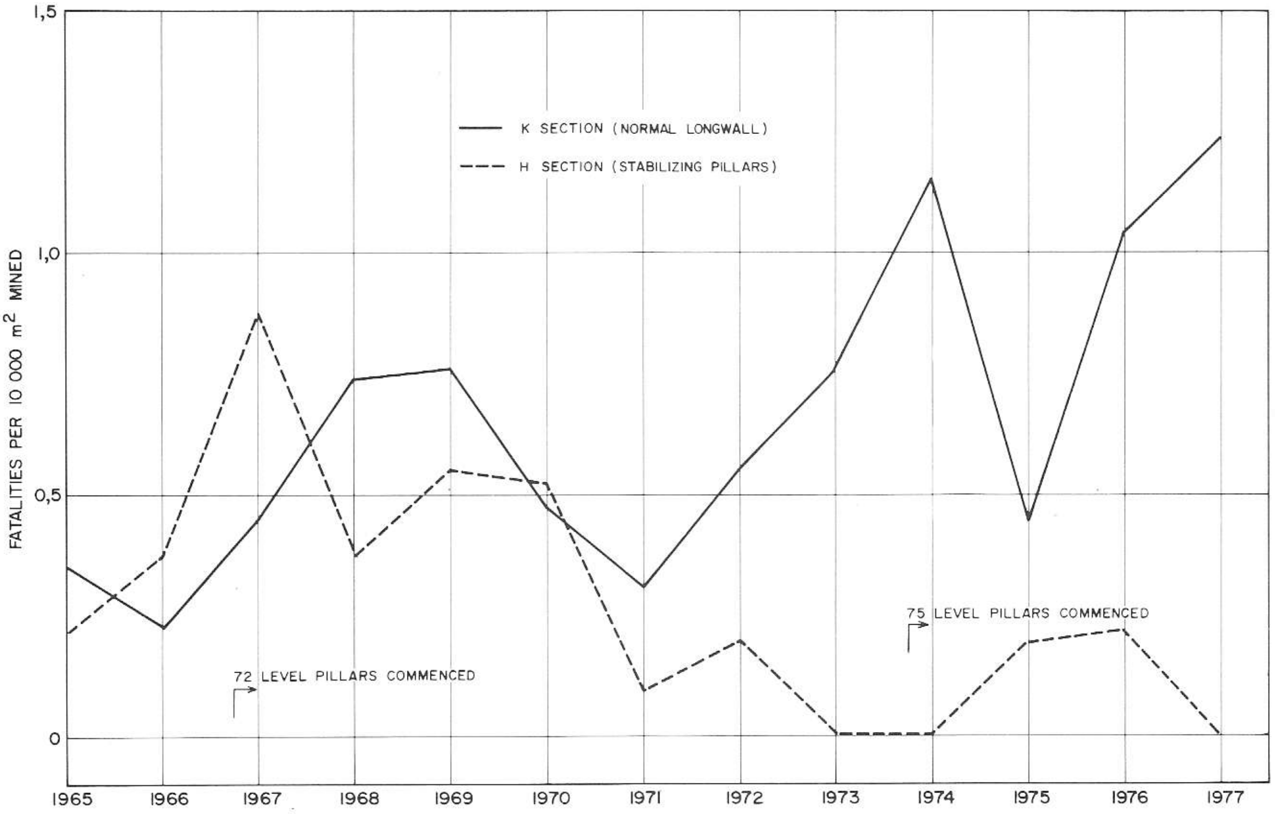

Fig. 3—Normalized casualty rates for H and K Sections, East Rand Proprietary Mines Limited

Theoretical Rationale

Deformation of the rock mass around deep-level gold mines has been shown to be well described by elastic theory[2]. The most important quantitative design parameter for stoping to have emerged from elastic theory is the energy release rate (E.R.R.), which is the spatial rate at which energy is released by the removal of highly stressed rock at the face. Inelastic effects in the immediate vicinity of the face dissipate this strain energy before the rock is actually mined, and result in rockburst activity and fracturing around the stope. It has been shown[5] that the extent and intensity of fracturing ahead of the face increase with increasing E.R.R. and that the increased incidence of rockbursts appears to be associated with higher values of E.R.R.[6]. Qualitatively, this relationship is now widely accepted.

Analytic solutions for the E.R.R. in several simple geometric situations show that a marked reduction in E.R.R. is achieved if long parallel pillars are left aligned in the direction of face advance[2]. For example, well-established strike pillars 45 m wide and spaced 225 m apart are expected to reduce the average E.R.R. by about 70 per cent. Pillars spaced closer to one another will reduce the E.R.R. even further. However, for the same extraction ratio, the pillars would have to be narrower and the risk of failure and possible instability would be increased.

It has been shown that the strength of pillars in South African coal mines[7] depends on the ratio of the width to the height of the pillar (w/h). For a w/h value of more than, say, 10 or 20, the pillar will be infinitely strong and the system stability will then be controlled by failure (or lack of failure) in the hangingwall and footwall. If little or no failure occurs, the rock mass can be considered to behave elastically, and estimates of E.R.R. can be used as an indication of expected rockburst activity.

After the introduction of stabilizing pillars at E.R.P.M., seismic events were reduced substantially for two areas protected by adjacent strike pillars. The reduction of 60 per cent and 75 per cent in the seismic energy released from these two areas correlated well with an estimated 70 per cent reduction in E.R.R.[8].

Geological Rationale

In addition to their principal role of restricting the volumetric convergence and so reducing the E.R.R., stabilizing pillars may serve to limit the magnitude of individual seismic events in a more direct manner. Since the mechanism of seismic events is not completely understood, the argument that follows is largely conjectural, but it appears logical and does seem to match past experience qualitatively.

The argument assumes that kinetic energy in the form of a shock wave is liberated from the strained rock mass by a sudden fracture along an essentially plane and continuous surface or by slip along an existing geological discontinuity. There is substantial evidence to show that such a planar rupture process is involved in many of the larger seismic events[9]. It is reasonable to assume that the magnitude of the event is related to the areal extent of the fracture or slip.

The main intention in longwalling is to distribute the induced stresses as uniformly as possible along the length of the longwall. Therefore, it follows that, if the stresses become critical for slip somewhere along the length of a longwall, they must be nearly critical everywhere else. Once started, the slip or fracture front will generate high stresses immediately ahead of itself, which will add to the near-critical condition already existing. This will create a dynamically unstable failure that will propagate itself along the longwall for as far as the stress condition is more or less uniform.

By providing zones of high compressive stresses acting perpendicular to the face direction, the stabilizing pillars would provide a 'clamping' effect that would halt the propagating unstable fracture or slip and limit the size of the associated seismic event. The buttress effect of stabilizing pillars along the length of a typical dip dyke being approached in a 'broadside' manner by the aligned faces of a limited longwall can easily be visualized — Fig. 4. The slight decrease in major principal stress and significant increase in the minor principal or 'clamping' stress compared with the ideal longwall case is illustrated in the strike sections of Fig. 4. The relative areas along the dyke contact that are liable to slip in terms of the criterion

$$\sigma_1 = 0 + 6\sigma_3$$

are shown in Fig. 5.

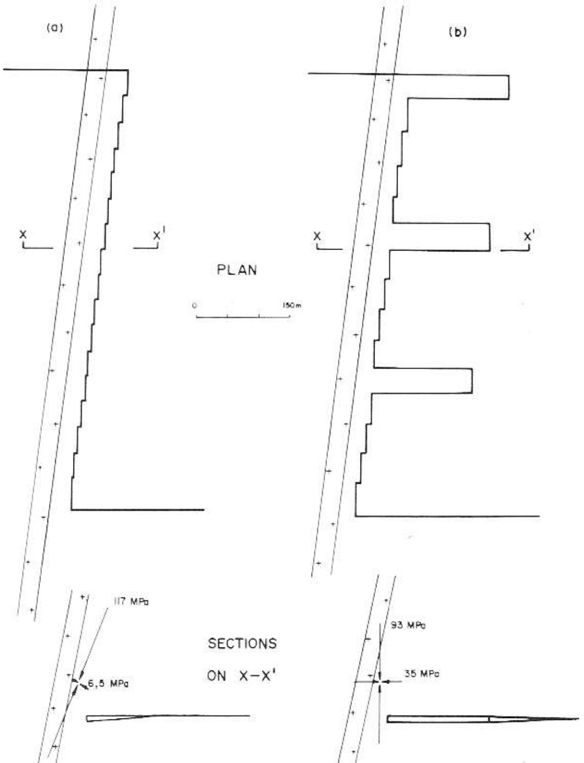

Fig. 4—Plan and sections of the computer-simulated geometry, illustrating the 'clamping' effect that stabilizing pillars have on a geological discontinuity parallel to a longwall face

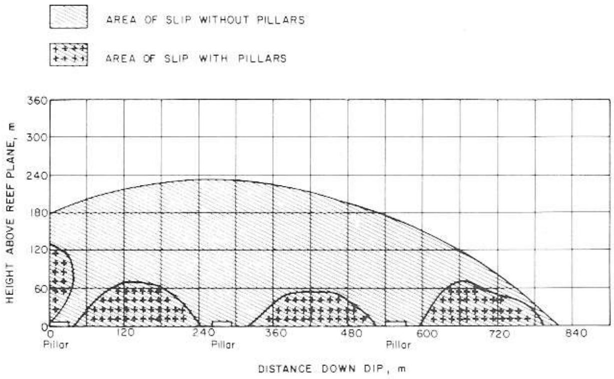

Fig. 5—Vertical dip section, showing areas where the shear-stress level is sufficiently high ($\sigma_1 > 6\sigma_3$) to sustain slip along the discontinuity of Fig. 4

Planning and Implementation

Since the adoption of stabilizing pillars means the permanent loss of ore reserve, it is necessary to make the loss as small as possible. At the same time, the reduction in energy change must be as large as possible. The spacing between pillars plays the dominant role in reducing the volumetric closure. In order to maintain a reasonable percentage extraction, the width of the pillar must be reduced as the spacing between pillars is decreased. To a large extent the spacing is determined by the existing mine layout, particularly the interval between levels, since there are compelling reasons for locating the pillars at some multiple of inter-level spacing.

There is no way of analytically determining the minimum width of pillar below which violent failure of the pillar itself might occur. The only guide that existed at the time was the experience of E.R.P.M., where the stabilizing pillars were probably conservatively large and rather widely spaced.

Elastic analyses were therefore considered essential to

(a) demonstrate that substantial changes in the E.R.R. could be achieved even at the existing late stage in the life of the mine,
(b) check that the stresses induced in the pillars did not reach obviously dangerous values,
(c) optimize the location of the pillars in some cases where the presence of suitably oriented dykes afforded the opportunity of incorporating a main dyke into the pillar itself.

Elastic Analyses

The well-known Chamber of Mines electrical analogue computer[2] provided the most convenient means of rapidly conducting the very comprehensive series of analyses that would form the basis of the detailed policy decisions that would have to be made.

The four remnant abutments and the two east and west boundary abutments were analysed individually at a scale of 30 m per analogue grid unit. The 60-unit grid thus permitted detailed examination of the stoping within an area of 1800 m by 1800 m, while the presence of stoped areas for an additional 900 m beyond the boundaries was more crudely recognized. Year-by-year changes in the configuration of each abutment, as well as the advances of the faces on the other side of the adjacent stoped areas, were analysed with and without the stabilizing pillars.

Four alternative configurations of stabilizing pillars were considered for the two abutments in the eastern half of the mine to determine the most suitable width and spacing of pillars. The chosen layout was then applied to the remaining four abutments for comparison in each case with the no-pillar alternative.

Altogether 186 analyses were conducted with the E.R.R. being taken as the significant parameter. Typical results are shown in Fig. 6. The improvement in E.R.R. of the strike stabilizing pillars at 270 m dip spacing is considerable. (The erratic fluctuations in some of the graphs are due to the sequence in which analogue pins were extracted and do not reflect real changes.)

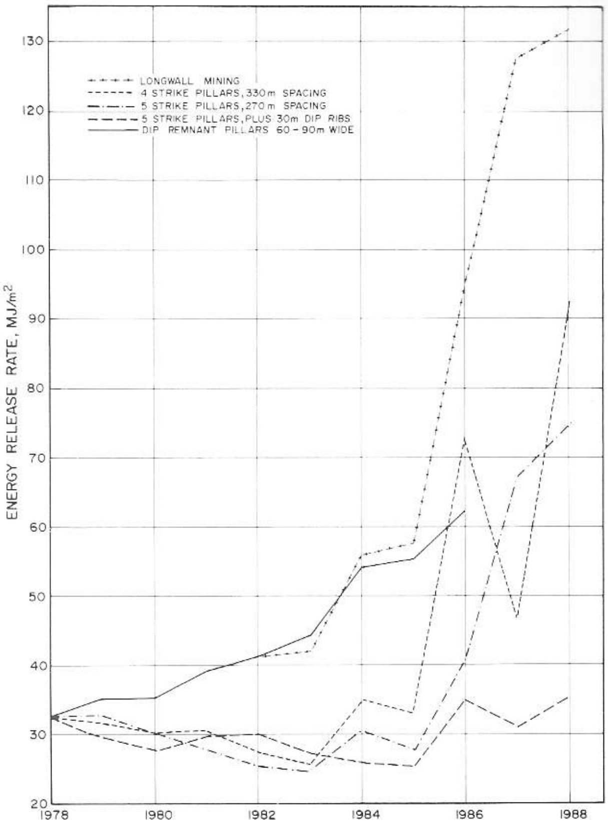

Fig. 6—The average energy release rate at yearly intervals for longwall mining and for various stabilizing-pillar configurations on B2-B3

The normal stress for each 30 m by 30 m block comprising the pillars was also determined from the analogue computer. Thus, the average stress for the fourth pillar down in B2–B3 abutment would be 330 MPa if it were made 60 m wide, and 500 MPa if 30 m wide. From a consideration of the percentage areas extracted, the corresponding value for a 45 m wide pillar would be about 375 MPa.

Based on a somewhat simplified argument, it was believed at that time that this latter stress value would represent a minimum safety factor of 1,5. The analogue-determined average stress for the 30 m wide southern boundary pillar between Blyvooruitzicht and Western Deep Levels was 600 MPa. The fact that this pillar appears to be completely stable substantiated the belief that the 45 m wide stabilizing pillars would also be stable. Thus, a series of 45 m wide strike pillars separated by approximately 200 m in the dip direction was adopted as the basic layout for the future (Fig. 7).

Since the acquisition in 1979 of the minicomputers for the seismic location system, the electrical analogue is no longer used by Blyvooruitzicht. Instead, a programme, which is briefly described in the following section, has been developed to analyse the distribution of various elastic quantities such as stress, strain, displacement, and E.R.R.

An example of an E.R.R. analysis is given in Fig. 8, in which the values are plotted yearly in the appropriate portions of the B2–B3 abutment as it is mined-out with and without stabilizing pillars. (Note that these values agree reasonably well with those indicated by the curves in Fig. 6.) The outline of the mining configuration was drawn by the computer from disk-stored data, which are also used to generate the equivalent grid-block outline. This mining outline data-disk is up-dated quarterly from the surveyors' mine plans, and is thus able to give current accurate analyses for any portion of the mine without delay.

Results

Although the managerial decisions and structural changes necessary for the introduction of stabilizing pillars can be made relatively quickly, the actual implementation and physical realization of these changes must necessarily be a long drawn-out process governed by the relatively slow rate of face advance. Consequently, it is still too early to expect to see conclusive evidence of success or otherwise. However, there are two areas in which early indications of success might be expected: seismicity and productivity.

Seismic Acitivity

During 1979 Blyvooruitzicht Mine installed its own seismic network to assist in the planning and monitoring of the extraction of the remaining reserves of Carbon Leader. Blyvooruitzicht was the first South African mine to embark on its own seismic research programme.

Geophones installed at 16 sites underground and on surface transmit signals in analogue form to a site on surface, where the history of ground motion (seismograms) is recorded in digital form by a Hewlett-

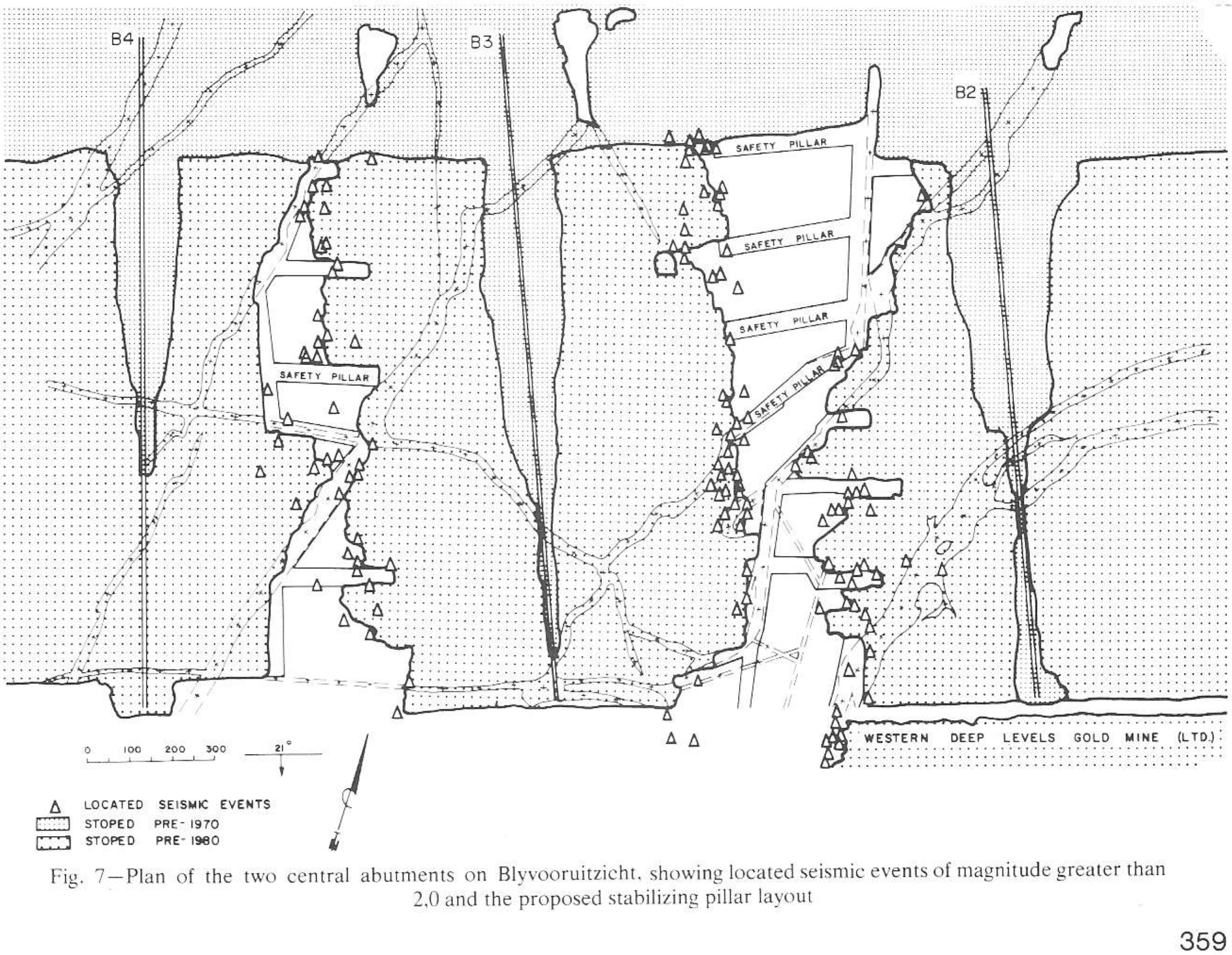

Fig. 7—Plan of the two central abutments on Blyvooruitzicht, showing located seismic events of magnitude greater than 2,0 and the proposed stabilizing pillar layout

Packard minicomputer system. A second computer is used to display the seismograms on a graphics screen, the arrival times of P and S waves are picked by hand, and locations are obtained by use of an interactive computer program. Location accuracy is about 20 m in plan in the centre of the mine, and perhaps 100 m near the boundaries. Richter magnitudes are estimated from durations of ground motion at up to 10 geophones of the mine network and up to 6 geophones of the nation-wide array of the South African Geological Survey. Coverage between May 1979 and June 1981 was 90 per cent, with most of the down-time caused by 'teething' problems during 1979. More than 4000 seismic events of Richter magnitude 1,0 and greater were located in Blyvooruitzicht and adjacent mines during that period.

Fig. 7 is a plan view of Blyvooruitzicht Mine showing positions as at December 1980. Locations of seismic events with magnitudes greater than 2,0 during the previous 18 months are shown. The few seismic events that were not located on active faces occurred on old faces or near known geological discontinuities. Most seismic activity clusters around the advancing faces between the B incline shafts below 16 level.

One of the main purposes of the seismic research facility at Blyvooruitzicht is to provide the data that will supply the answers to the following two questions:

1. Will the proposed strike pillars show any signs of instability?
2. Will the strike pillars cause a reduction in seismic activity near the adjacent faces?

During the period considered so far, the answer to the first question appears to be in the negative since no large seismic event has been located on a pillar.

Detailed analysis is required before the second question can be answered. Seismic activity can perhaps best be measured in terms of the seismic moment (M_O), which is the total change in strain caused by the release of strain energy at the source of the seismic event.

Data from E.R.P.M. have shown[8] that the sum of the seismic moments for all seismic events in the three stoping areas below the stabilizing pillars on 69, 72, and 75 levels (Fig. 2) during a three-month period was related to mining activity by

$$\Sigma M_O = G\Delta V, \qquad (1)$$

where G is the modulus of rigidity, and
ΔV is the expected volume change resulting from elastic deformation of the stope as mining proceeds.

It was found that the well-established 60 m wide strike pillars at E.R.P.M. reduced the overall seismicity by approximately 70 per cent, as expected from equation (1). It was possible to approximate the faces by simple shapes, and analytical solutions sufficed for the estimation of ΔV.

As seismic moments have yet to be determined directly for seismic events at Blyvooruitzicht, an empirical relationship obtained for E.R.P.M.[10] was used:

$$\log M_O = 10{,}7 + 1{,}2\ M, \qquad (2)$$

where M_O is in units of newton-metres, and
M is the Richter magnitude.

This relationship might be in error for Blyvooruitzicht events owing to differences in the geological structure between E.R.P.M. and Blyvooruitzicht, which are some 100 km apart, but the relative accuracy of the estimates of seismic moment within Blyvooruitzicht should be adequate.

Volume changes due to mining were estimated by use of

$$V = 2\Delta A . E/\sigma_1,$$

where ΔA is the incremental area mined in square metres,
E is the average E.R.R. for this area in megajoules per square metre,
σ_1 is the ambient maximum principal stress in megapascals, and
V is expressed in cubic metres.

A computer programme REEFS, based on the displacement discontinuity method[11], was used to estimate values for E.R.R. for the entire mine. REEFS determined stope convergence for the blocks of a 60 m by 60 m grid, each block being 15 m on a side, for separate overlapping areas of the mine, each time considering the effect of stope convergence of other grid blocks at distances up to 1,8 km away. REEFS considered approximately 1000 separate areas to give the data base for this study. In addition to the average stope convergence in mined-out blocks, the values of normal stress on the reef plane in unmined blocks were also calculated and stored.

The E.R.R. values were then estimated from

E.R.R. = ½ stress in unmined block × convergence when mined.

An example of the distribution of E.R.R. is given in Fig. 8.

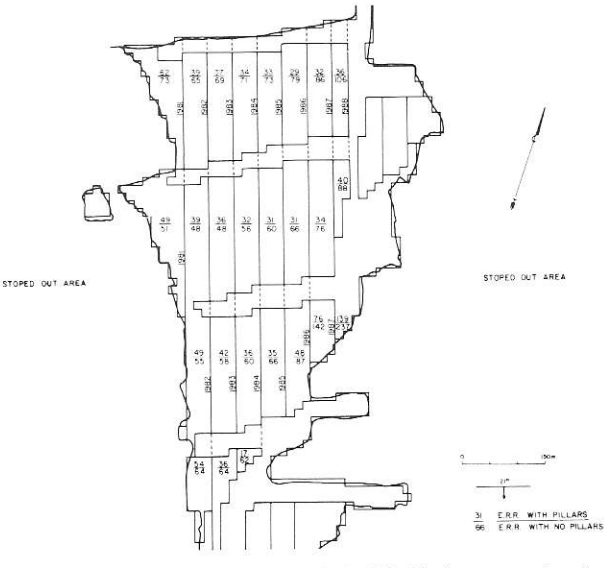

Fig. 8—Plan of the top portion of the B2-B3 abutment, showing the E.R.R. values as it is stoped from the B3 side with and without stabilizing pillars

Volume changes associated with seismic activity and with elastic deformation are shown in Fig. 9 for four areas in the mine that can be identified in Fig. 7. Stepped curves represent cumulative seismic moment

(ΣM_O), the horizontal lines indicate aseismic time periods, and the vertical lines indicate seismic events, the length of the line being proportional to the seismic moment. The magnitude of the largest seismic event in each six-month period is shown. The smooth curves are the elastic closure (V) estimated from equation (3) and plotted to the same scale. The crosses indicate the volume changes normalized to the same stoped area that would have occurred if the pillars had been mined.

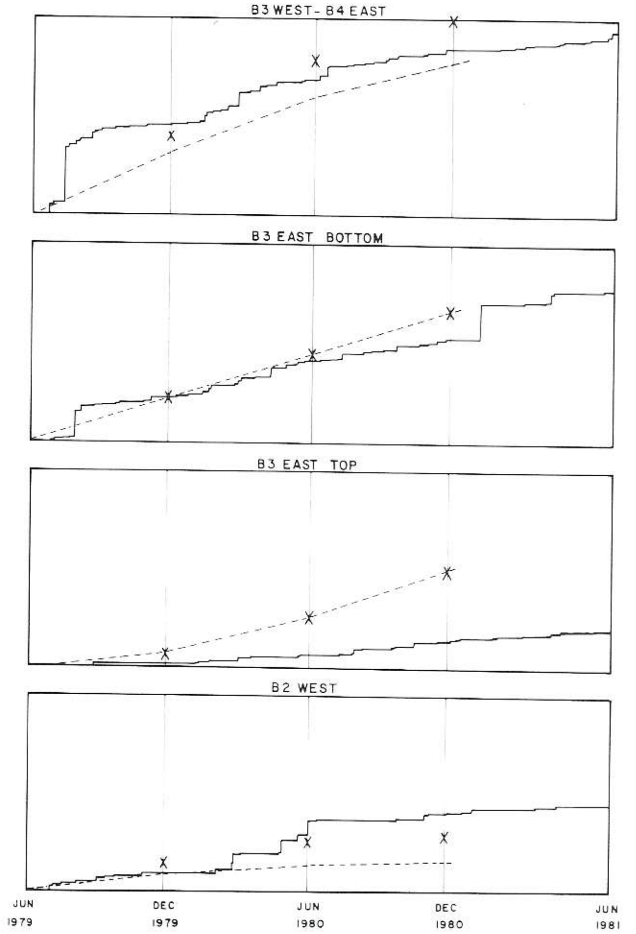

Fig. 9—A comparison of the cumulative seismic moment (stepped curve) with the elastic volume change due to mining (smooth curve). Crosses show the volume change that would have occurred had stabilizing pillars not been left

The four areas selected for the cumulative activity plots were the stoping between B4 and B3, B3 East between the top two proposed strike pillars, B3 East below that area, and B2 West. The seismic activity between B4 and B3 and around the lower section of B3 East followed the plots for elastic deformation remarkably closely. The first area shows a consistent reduction in seismic activity as the pillars have become established.

The upper section of B3 East was seismically quieter, and the faces on B2 West were seismically more active, than predicted by equation (1). Geologically, these two areas are unusual for Blyvooruitzicht, the first being exceptionally uncomplicated, whereas stoping on B2 West has been complicated by numerous geological discontinuities. The other two areas considered were mined in more typical geological conditions.

The plots of cumulative moment in Fig. 9 indicate that the strike pillars at Blyvooruitzicht are beginning to reduce the overall level of seismic activity, even though the effect is somewhat limited at this early stage. Further data, particularly in areas where dykes are being left behind as part of the pillars, should indicate clearly whether the pillars have performed according to expectations.

Production and Accidents

The two matters of most concern to management are, naturally, production and safety. The effects on these will determine the success or otherwise of any major change in policy or layout. Preliminary indications of the effect that the introduction of stabilizing pillars has had on Blyvooruitzicht are given in Fig. 10. This shows the rockburst casualty rate per 10 000 m^2 stoped below 16 level for each year since 1971, and the average monthly face advance for each quarter during the same period.

The general decline in face advance and the increase in casualty rate from 1974 to 1977 are largely attributable to the worsening conditions as the longwalls encountered more dykes while gradually approaching the final remnant stage.

The abnormally high casualty rate in 1977 is a direct consequence of the serious rockbursts that occurred in August and September of that year. The fact that the lowest-ever advance was recorded in the last quarter of the year, when the normal annual cycle shows a low value in the March quarter, is attributable to the same cause.

It is probable that the strong, sustained increase in face advance after that period is due more to the change from diagonal scraping to strike-gully cleaning than to any improvement in ground conditions. The increase in gold price, which led to a greater concentration of mining activity in the easier areas above 16 level, possibly also played a part.

Conclusions

The adoption of a layout using stabilizing pillars represented a major change in company policy. It involved a commitment to the permanent abandonment of some 14 per cent of the remaining ore reserve, which, at the then-prevailing gold price of \$160 an ounce, meant the loss of 71 million rands in total potential revenue.

The decision to change was an acknowledgement of the fact that it is not possible for all the available ore in deep mines to be extracted safely. It is correct planning, therefore, to leave the minimum amount of ore *in situ* in such a manner that it will enable the remaining ore to be stoped under manageable mining conditions.

There is no way of knowing how much of the remaining gold could have been mined with any degree of safety by the old system — certainly not all of it. Indeed, it is debatable whether as much gold would have been lost in the final unmineable remnants

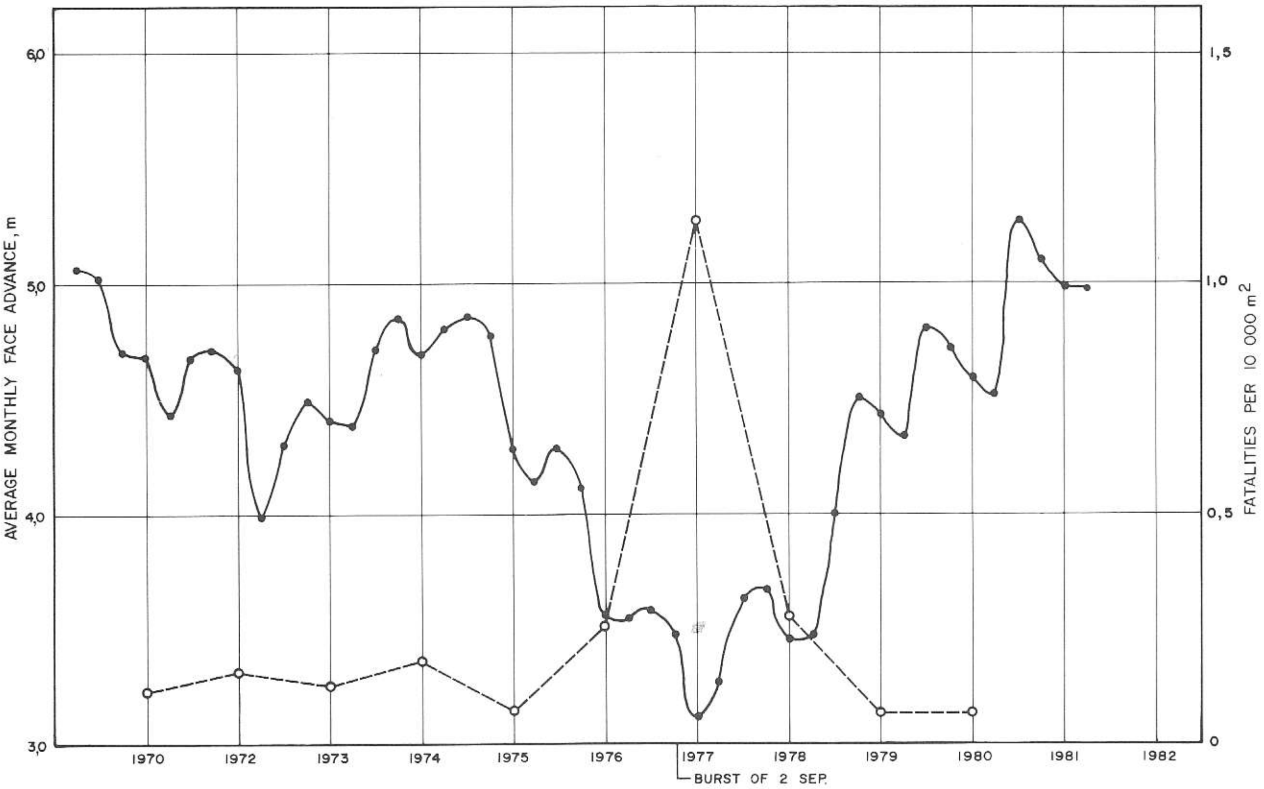

Fig. 10—Quarterly average of monthly face advance and annual casualty rate for Blyvooruitzicht from 1970 to 1980

as that now deliberately left in the stabilizing pillars.

It is not possible, before the end of the life of a mine, to make a proper assessment of whether the stabilizing pillars did, in fact, provide adequate protection for the removal of the 86 per cent of ore that was considered exploitable.

It is too early at present to make more than a tentative preliminary assessment of the success of the change in policy. It is true that no rockbursts of anywhere near the severity of the three events of August–September 1977 have occurred since the stabilizing pillars became established. On the other hand, it is well known that the seriousness of a rockburst incident is often determined fortuitously, and that a statistically-based comparison of such small numbers of events cannot be well-founded.

The improvement in productivity indicated so far (Fig. 10) must to some extent be associated with improved ground conditions and fewer rockburst delays, which might be a direct consequence of the stabilizing pillars. However, certain mining changes that were necessary for the introduction of strike pillars, such as the change from diagonal gullies to strike-scraper gullies, may have played the dominant role in improving the rate of face advance.

However, there is no doubt in the minds of the persons involved that the decision to adopt a stabilizing-pillar layout was the correct one in the prevailing circumstances, and that the future will justify their present faith.

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References

1. HILL, F.G. A system of longwall stoping in a deep-level mine, with special reference to its bearing on pressure bursts and ventilation problems. Johannesburg, Association of Mine Managers of South Africa, *Proceedings* 1942—45, Vol. 1. Jan. 1944. pp. 257—276.
2. COOK, N.G.W., HOEK, E., PRETORIUS, J.P.G., ORTLEPP, W.D., and SALAMON, M.D.G. Rock mechanics applied to the study of rockbursts. *J. S. Afr. Inst. Min. Metall.*, vol. 66. 1966. pp. 435—528.
3. STEELE, K.E., and ORTLEPP, W.D. Rockbursts: the problem and management countermeasures on E.R.P.M. Ltd. Johannesburg, Association of Mine Managers of South Africa, *Papers and Discussions*, 1972—73. pp. 225—261.
4. SALAMON, M.D.G., and WAGNER, H. Role of stabilizing pillars in the alleviation of rockburst hazards in deep mines. *Proceedings 4th International Congress, International Society of Rock Mechanics*. Montreaux, 1979. vol. 2, pp. 561—566.
5. ADAMS, G., and JAGER, A.J. Petroscopic observations of fracturing of rock ahead of stope faces in deep-level gold mines. Johannesburg, Chamber of Mines, *Research Report* 17/79.
6. HODGSON, K., and JOUGHIN, N.C. The relationship between energy release rate, damage and seismicity in deep mines. *Failure and breakage of rocks*. Fairhurst, C. (Editor). New York, AIME, 1967.
7 SALAMON, M.D.G., and MUNRO, A.H. A study of the strength of coal pillars. *J. S. Afr. Inst. Min. Metall.*, Sep. 1967.
8. McGARR, A., and WIEBOLS, G.A. Influence of mine geometry and closure volume on seismicity in a deep level mine. *J. Rock Mech. Min. Sci. Geomech. Abstr.*, vol. 14. 1977. pp. 139—145.
9. ORTLEPP, W.D. The mechanism of a rockburst. *Proceedings of 19th U.S. Rock Mechanics Symposium*. Stateline, Nevada, May 1978.
10. SPOTTISWOODE, S.M., and McGARR, A. Parameters of tremors in a deep-level gold mine. *Bull. Seis. Soc. Amer.*, vol. 65, no. 1. Feb. 1975. pp. 93—112.
11. CROUCH, S.L. Analysis of stresses and displacements in underground excavations: an application of the displacement discontinuity method. Minnesota, University of Minnesota, *Geomechanical Report* 1976b.

Presenter: W.D. Ortlepp

Discussion

A.G. Mann: Is the geometry of the pillar critical, or is it determined as a mining convenience?
W.D. Ortlepp: Yes, the geometry is critical in that the pillar should be parallel to the line of advance of the face to be effective.

W.M. Otto: With the introduction of stabilizing pillars, can a more flexible approach be used with regard to face shape in terms of leads and lags?
W.D. Ortlepp: Yes, it has been found that it is no longer necessary to maintain the rigid longwall shapes.

D.G. Dalton: When mining at greater depths, will there be a danger from the failure of stabilizing pillars?
W.D. Ortlepp: At East Rand Proprietary Mines, very few seismic events have been recorded in the area of stabilizing pillars, although the largest event was associated with the probable failure of a pillar. However, pillar failure, even at depth, is not a serious danger as energy release affects back areas rather than faces.

E.R. Tupholme: Would the same effect obtained with strike pillars not be obtained by leaving systematic pillars on dip?
W.D. Ortlepp: Yes, as previously stated, the stabilizing pillar should be parallel to the line of advance of the working face.

A.N. Brown: Many of the major rockbursts are caused by the presence of discontinuities such as dykes. Can one combine the stabilizing pillar and discontinuities to alleviate rockburst problems?
W.D. Ortlepp: Wherever applicable, the stabilizing pillars are located to embrace discontinuities; for example, cushion strips are left alongside dykes to reduce the effects of rockbursts.

D.H. Diering: What effect have pillars had on ventilation?
W.D. Ortlepp: At Western Deep Levels, 15 m wide slots have been driven at 120 m intervals along the strike pillars to facilitate ventilation. The leaving of stabilizing pillars has had a very definite negative effect on the ventilation of longwalls. Whereas, before, the ventilating air duct had to go up about 500 m of longwall face, it now has to traverse anything between 1000 and 1500 m.
A.N. Brown: The provision of ventilation connections through stabilizing pillars is a hazardous job and has the detrimental effect of reducing the pillar size. Perhaps the boring of tunnels in the hangingwall or footwall would be a more effective way of overcoming ventilation problems.

S. Budavari: It is well known that, at the beginning of this century, rockbursts were associated with the failure of pillars in the relatively shallow workings of our gold mines. In the present deep-level workings, pillars are left to maintain the energy release rate at an acceptable level. Where these pillars are formed, the rate of extraction is relatively low at the moment; therefore, the pillars may not be fully loaded. Would the authors comment on the possibility of the failure of these pillars, hence the recurrence of the situation mentioned above, once the overall rate of extraction reaches a higher figure?
W.D. Ortlepp: The possibility of failures of this nature is a real one, but experience so far at East Rand Proprietary Mines shows that, with adequate pillar dimension, no great dangers in this respect will arise. It is believed that the pillar dimension at Blyvooruitzicht is also adequate. There may be a critical dimension below which it would be inadvisable to further decrease the width.