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COMRO

THE INFLUENCE OF BACKFILL ON SEISMICITY

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PREFACE

A major motivation for placing backfill in deep mines is the expectation that, as with stabilizing pillars, there should be a reduction in the rate of mining-induced seismicity, together with a concomitant reduction in the frequency of rockbursts. Moreover, because of the increased area support provided by backfill, together with the work-hardening compression characteristics of backfill, a reduction in the severity of rockburst damage should occur.

This report addresses the first motivation mentioned above, namely, whether backfill reduces the frequency and size of seismic events in deep mines. Three case studies are evaluated and it appears that the results are ambiguous. This is partly due to the quality of the seismic data available, but also to the fact that the areas being compared differ with respect to important parameters such as geology, the amount of mining and the mining method. These factors are now being evaluated by COMRO in controlled field experiments at two mines in the Carletonville district.

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SUMMARY

In this report the seismicity at three different sites was investigated during mining with backfill and mining without backfill in order to evaluate the effectiveness of backfill as a regional support in reducing seismicity. The seismic parameters evaluated are the total number of seismic events and the total energy released, the number of events and energy released normalised to area mined, MINSIM-D derived ERR values, b values and γ values.

The results indicate, although not conclusively, that the seismicity has been reduced in areas where backfill has been placed. A factor complicating the evaluation of backfill on seismicity is the effect of geological structures on seismicity.

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1 INTRODUCTION

While considerable research has been carried out into the *in situ* behaviour of backfill and the surrounding rock mass, the effect of backfill on seismicity has not been adequately quantified.

Gay *et al.* (1988) reported some findings on the effect of backfill on seismicity based on data from two areas of West Driefontein gold mine. They found that, although more events occurred in the backfilled area than in the conventional stope, these events were smaller in magnitude and energy was released at a more uniform rate than in the unfilled stopes. In the unfilled stopes the rate of seismic energy release was irregular with periods of relatively little seismicity punctuated by larger events. They did, however, also note that the geology could have influenced these results and that more reliable data were necessary.

This report looks at various aspects of the seismicity recorded at three different sites during mining with backfill and mining without backfill in an effort to determine the effectiveness of backfill as a regional support in reducing seismicity. Some of the problems associated with this type of analysis will also be highlighted.

2 SITE INFORMATION

Data recorded at three different sites have been used in this analysis.

2.1 West Driefontein #5 West

The first set of data was recorded using a minewide seismic system on West Driefontein gold mine. The area considered covers the 5W shaft pillar where the Carbon Leader Reef is being mined at a depth of approximately 2 000 m. The reef dips at about 21 ° south through the shaft pillar which is intersected by two seismically active dykes with throws of 5 m and 40 m, respectively (see Figure 1).

Mining of the shaft pillar began in May 1984 and ceased three months later as a result of increased seismicity levels. In August 1986 mining began again with the introduction of backfill. A decision was taken by the mine that regular face shapes should be maintained at the expense of rapid face advance. This resulted in an average face advance of 4 m per month.

Dewatered tailings backfill was used in conjunction with timber packs in panels and hydraulic props were installed at the face as local support units. Classified tailings backfill was introduced in place of dewatered tailings at the beginning of 1988. The backfill was placed between 5 and 8 m from the face and about 70 per cent backfilling was achieved.

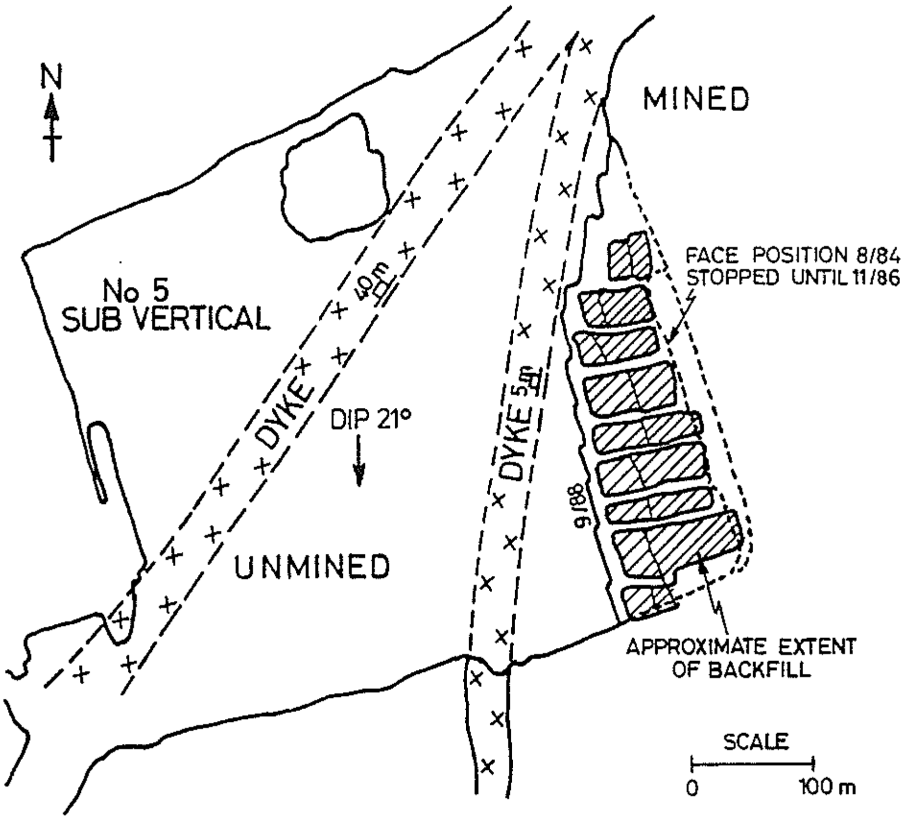

Figure 1 PLAN SHOWING THE GEOLOGY AND MINING LAYOUT OF WEST DRIEFONTEIN # 5 WEST

The seismic data used for the analysis cover the period May 1984 to October 1988. The network is able to record events in the magnitude range -1.0 to 5.0. Data are therefore available for a three month period when mining took place without backfill, a two year period during which no mining took place and a two year period during which mining took place with backfill. The fact that data are available for the period during which no mining took place means that it has been possible to obtain an idea of the 'background' seismicity. This is probably delayed seismicity as a result of closure and the release of stresses in the area mined during the initial three month period.

2.2 Western Deep Levels

The second set of data was recorded at two adjacent longwalls on Western Deep Levels gold mine. In this area the Carbon Leader Reef dips at 22° south and the up dip panel is being mined at a depth of approximately 2 500 m. The area is cut by a number of dykes and faults which have associated seismicity (see Figure 2).

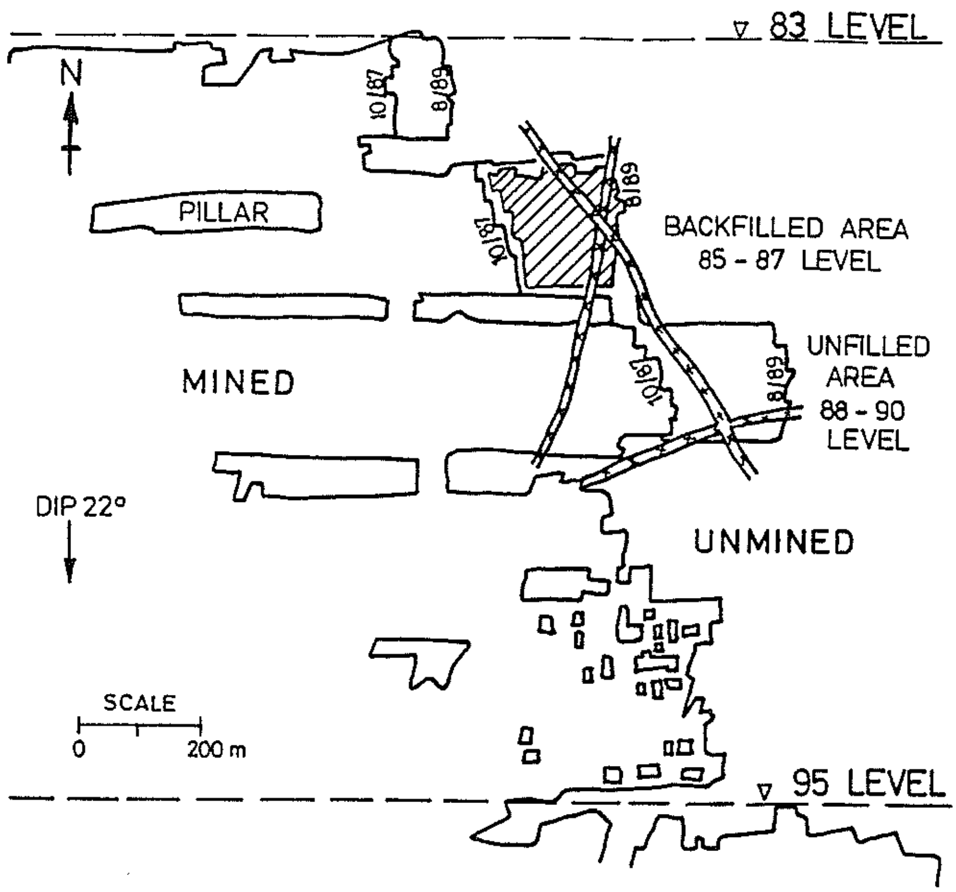

Figure 2 PLAN OF WESTERN DEEP LEVELS SHOWING FACE POSITIONS AT 10/87 AND 8/89. GEOLOGICAL FEATURES IN 85 - 90 LEVEL ARE SHOWN

88-90 Level East is being mined without backfill, while 85-87 Level East has been mined using classified tailings backfill since 1987. Hydraulic props are placed at the face and timber packs are used in the gullies. The backfill is placed on average 7 m back from the face and between 60 and 70 per cent backfilling has been achieved. The face advance is between 10 and 12 m per month.

The data were recorded using a minewide seismic system which detects and locates more than 600 events in the magnitude range -0.5 to 5.0 per month. Data were obtained for the period October 1987 to December 1989, which includes the mining of a dyke.

2.3 Vaal Reefs 2K Area

The third set of data was recorded using the Klerksdorp regional seismic network and comes from the 2K area of Vaal Reefs gold mine. The area under consideration is intersected by numerous faults and dykes which have associated seismicity. The reef lies at a depth of approximately 2 600 m (see Figure 3).

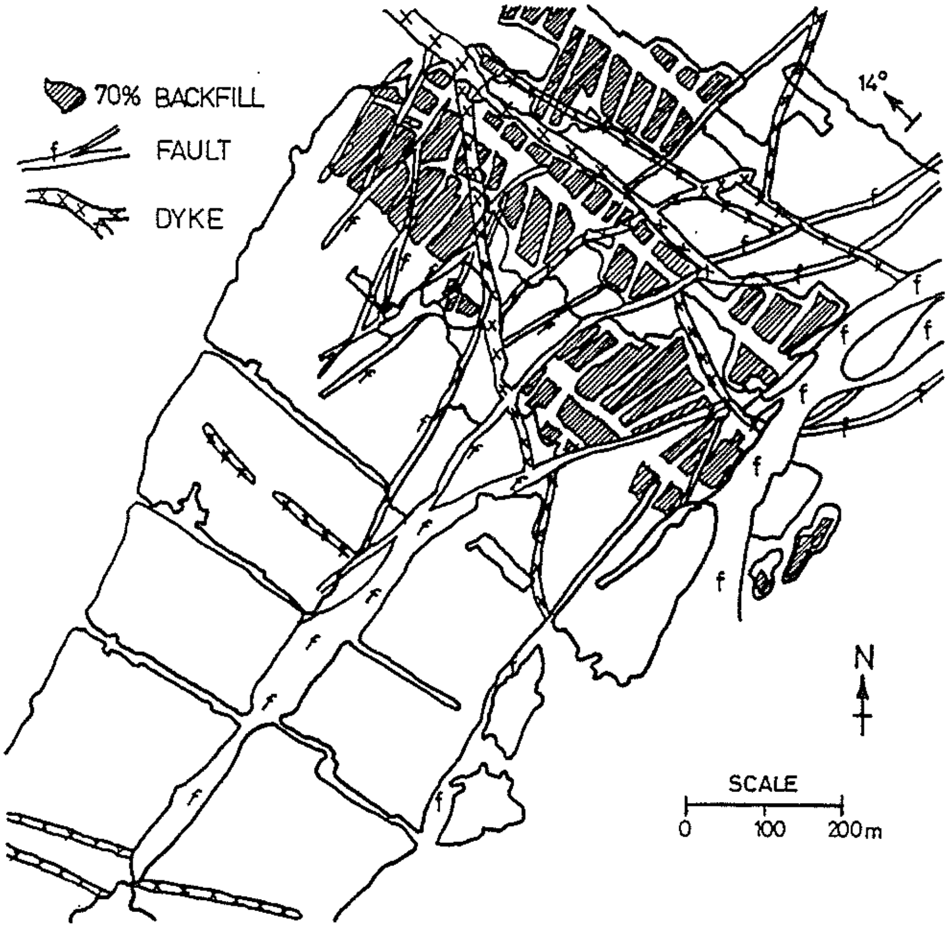

Figure 3 PLAN OF VAAL REEFS 2K AREA SHOWING GEOLOGY AND MINING LAYOUT

Scattered mining without backfill took place in this area from 1978 until January 1984 after which classified tailings backfill was introduced. Packs are used in the gullies and some hydraulic props are placed at the face. The backfill is placed between 4 and 8 m from the face and 70 per cent backfilling has been achieved.

The data covering all seismic events in the magnitude range 0 to 5.0 for the period January 1978 to December 1989 have been obtained. Although the backfill was placed in the first half of 1984, the period classified as mining with backfill has been taken as July 1984 to December 1989. This is to allow the backfill to take effect.

3 DATA SELECTION

The purpose of this study is to obtain an objective comparison between the seismicity recorded during mining without backfill and that recorded during mining with backfill. It should be noted that:-

i) large seismic events are known to cause greater loss of life and production than small events. Mine tremors with magnitude greater than three involve failure dimensions of at least several hundred metres.

ii) a high percentage of seismic events with magnitude greater than 2.5 have been found to occur close to dykes or faults, which are either approached or left by mining. The seismicity associated with dykes is thought to result from movement along a plane of weakness at the dyke-host rock contact. Spottiswoode (1981) found dykes to be at least twice as active seismically as the surrounding quartzites.

Thus, for meaningful results the data selected for analysis should be from two areas with virtually identical geological features. These data sets are obviously very difficult to obtain.

Analysing backfill-seismicity data is also complicated by the fact that there is often no reference level of seismicity against which any possible changes due to backfill can be measured.

The following discussion highlights the factors which complicate comparisons between backfilled and unfilled situations in the present data sets.

3.1 West Driefontein #5 West

Geology plays an important role in the level of seismic activity recorded at this site. An increase in seismicity is expected as mining approaches the dyke. In addition, only three months of data are available for mining without backfill, while data from mining with backfill have been accumulated over two years. These time periods are not comparable. Evaluation of backfill performance should rather be made on a long term basis with comparable periods of mining with and without backfill.

3.2 Western Deep Levels

A number of faults and dykes intersect this area and the largest seismically active dyke has been mined through in both the backfilled and the unfilled panels.

However, Lenhardt (1989) has found that the length of face in the dyke governs the extent of increased seismicity. Since the dyke runs approximately parallel to the dip direction, a large length of face will be in the dyke at any particular time. This means that a large increase in seismicity is expected as mining advanced through the dyke.

Thus, although the data covering the mining of the dyke in the unfilled and backfilled panels are available, they have been excluded to keep the analysis simple. The data set therefore covers the 18 months between the mining of the dyke in the unfilled panels (11/87) and the mining of the dyke in the backfilled panels (4/89). This means that no major geological discontinuity was mined by either a backfilled or an unfilled area for the time period under consideration.

3.3 Vaal Reefs 2K Area

The geological structure of the area covered during mining without backfill (7/78 - 6/84) is less complicated than the area covered during mining with backfill (7/84 - 12/89).

4 RESULTS

Essentially the same parameters have been calculated for each data set. In addition to standard statistics, such as the total number of events, the total area mined and the total energy released, normalised values have been calculated. MINSIM-D derived ERR values, b values and γ values (see Appendix I) are also included.

The results from each data set are presented and discussed in this section.

4.1 West Driefontein #5 West

Table 1 contains a summary of the seismic data from this area. A column containing data recorded during the period when no mining was taking place has been included. This information provides a measure of the background seismicity, probably resulting from the release of stresses at the dyke/quartzite contact due to closure in the area mined during the previous three months.

As has been noted, the time periods for mining with backfill and mining without backfill are not comparable. These unequal time periods also result in large differences in the total areas mined. The number of events occurring within each magnitude range are listed in Table 1, but, without some correction for the differences in the size of the data sets, these values are meaningless. They have therefore been normalised by considering the number of events per 1 000 m^2 mined.

These normalised values provide information on the general seismicity levels. From Table 1 it is obvious that the period of mining with backfill experienced higher seismicity levels within all magnitude ranges than the period of mining without backfill. This increase may be due to mining closer to a seismically active dyke than during the period of mining without backfill (see Figure 1).

Similar results are obtained if the total seismic energies released during the two time periods are calculated. However, one may argue that the seismicity for the 24 months of no mining is residual energy being released as a result of mining during the previous three months. The released energy of 4.90×10^3 MJ should therefore be included in the 'no backfill' data set. Values calculated with this argument are marked with an asterisk in Table 1. The normalised energy release value (MJ/1 000 m^2) is then smaller for the period of mining with backfill than for the period when no backfilling was taking place.

Table 1 SEISMIC PARAMETERS FOR WEST DRIEFONTEIN #5 WEST

	No Mining	No Backfill	Backfill
Time Period No. of Months	9/84-8/86 24 months	5/84-8/84 3 months	9/86-10/88 26 months
Area Mined (m^2)	-	3 890	23 960
Total Events Events 1 < M < 2 Events 2 < M < 3 Events M > 3	37 5 2 1	32 5 - -	760 96 11 1
Total / 1 000 m^2 M > 1 / 1 000 m^2 M > 2 / 1 000 m^2	- - -	8.2 1.3 -	31.7 4.5 0.5
Total Energy Released (MJ) Energy / 1 000 m^2	4.90×10^3* -	84.61 1 281.39*	1.80×10^4 751.25
Ave ERR (MJ/m^2)	-	47.0	36.2
b Value Error in b	0.68 0.22	1.01 0.41	1.01 0.09
γ_M	-	0.854*	0.501

* See text

The high ERR value obtained during mining without backfill is one of the reasons why mining operations were ceased in this area after three months. Although the seismicity levels were higher during mining with backfill, no corresponding increase is seen in the ERR values. This is because the increase in seismicity is probably associated with mining approaching the dyke, and geological discontinuities such as faults and dykes cannot be modelled with MINSIM-D.

The b value listed in Table 1 is a frequency magnitude statistic which is related to the number of events within each magnitude range (see Appendix I). The larger the b value, the smaller the number of large events within a seismic population. The error in the b value is inversely proportional to the square root of the size of the data set.

The small b value for the period of no mining implies that there is a large ratio of large to small events. Since large events are known to be more damaging and dangerous, this is not an ideal situation. The backfill seems to increase this value to the value associated with the period of mining without backfill, bringing the relative number of large events down. However, the large error in the b value for mining without backfill means that no definite conclusions can be made about the effectiveness of backfill in reducing the number of large events.

It is well known that there is a relationship between the volume of rock mined and the amount of seismic energy released. In geologically simple mining areas this relationship is approximately linear. The proportionality factor in this relationship is the γ value (see Appendix I). The smaller γ value for mining with backfill is encouraging as it means that the likelihood of the rock to deform seismically has been reduced with the introduction of backfill.

4.2 Western Deep Levels

Initially existing data from this area for the period 1/85 to 10/87 were considered. At that time 93-95 level was being mined and backfilled with comminuted waste, while 83-90 level was being mined without backfill (see Figure 4). The results of this study are given in Table 2.

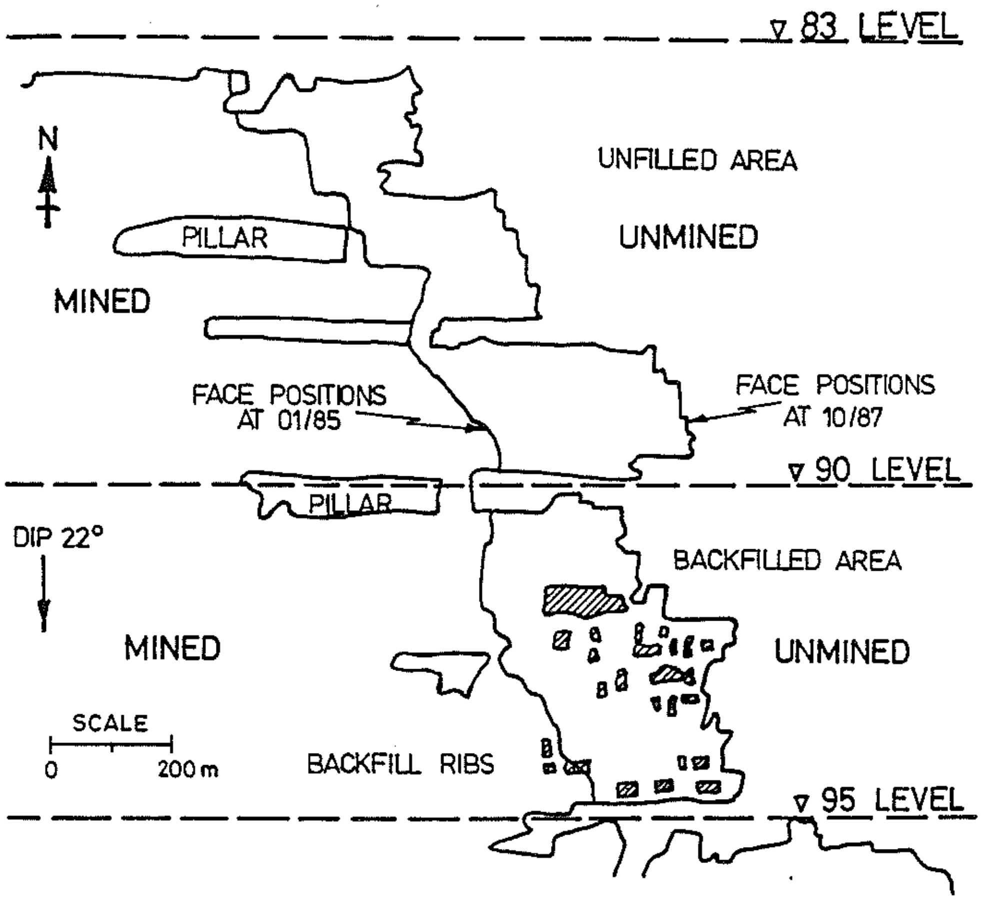

Figure 4 PLAN OF WESTERN DEEP LEVELS 83 - 95 LEVEL

Table 2 SEISMIC DATA RECORDED IN THE AREA OF WESTERN DEEP LEVELS SHOWN IN FIGURE 4

Time Period 1/85 - 10/87	No Backfill	Backfill	% Reduction
Area Mined (m^2)	144 596	126 137	-
Events / 1000 m^2	1.89	1.50	21 %
Events > 1 / 1 000 m^2	0.75	0.47	36 %
Events > 2 / 1 000 m^2	0.19	0.09	53 %

These results imply that there is a decrease in seismicity in areas with backfill and this reduction increases for larger magnitudes. These are encouraging results since the large events cause most damage.

Table 3 contains a summary of the seismic data for 85 - 90 level East for the period 11/87 to 4/89. It was decided that, in order to reduce the geological bias in the data, all large events which located on geological structures should be excluded from the data set. The events which have been excluded are a magnitude 2.8 which occurred on a fault in an unfilled panel, and a magnitude 3.1 which occurred on a dyke in a backfilled panel. The values given in brackets are the values obtained if these events are not excluded from the data set. Exclusion of these data will have the greatest effect on the energy values (since the energy-magnitude equation is logarithmic).

Identical time periods have been considered here and the two total areas mined are comparable. The number of events occurring in the backfilled panels is considerably larger than those occurring in the unfilled panels. This difference is not a function of magnitude. This means that the increase in the number of events does not just occur within the lower magnitude range.

The values for total energy released are an order of magnitude larger for the backfilled panels than for the unfilled panels.

The ERR values prior to the time when backfilling began are considerably smaller for the unfilled panels than for the backfilled panels. After 18 months of backfilling the values are approximately equal. Therefore, ERR values and seismicity levels do not appear to be directly related.

The increased seismicity in the backfilled panels manifests itself in a reduction in the b value, suggesting a higher ratio of large to small events.

The γ values are too small for any conclusions to be drawn.

Table 3 SEISMIC PARAMETERS FOR WESTERN DEEP LEVELS FOR 85-90 LEVELS EAST

	No Backfill 88-90 Level East	Backfill 85-87 Level East
Time Period No. of Months	11/87-4/89 17 months	11/87-4/89 17 months
Area Mined (m^2)	35 617	32 916
Total Events Events 1 < M < 2 Events 2 < M < 3 Events M > 3	44 (45) 10 (10) 0 (1) 0	107 (108) 19 (19) 4 (4) 0 (1)
Total / 1000 m^2 M > 1 / 1 000 m^2 M > 2 / 1 000 m^2 M > 3 / 1 000 m^2	1.2 (1.3) 0.3 (0.3) 0.0 (0.0) 0.0	3.3 (3.3) 0.6 (0.6) 0.1 (0.1) 0.0 (0.0)
Total Energy Released (MJ) Energy / 1 000 m^2	98 (1 098) 2.75 (30.83)	1 068 (3 523) 32.45 (107.03)
ERR (MJ/m^2) Before Backfill 3/89	 12.8 11.2	 17 11.3
b Value Error in b	0.70 (0.57) 0.22 (0.19)	0.57 (0.54) 0.13 (0.12)
γ_M	0.002 (0.021)	0.022 (0.071)

Figure 5a shows the variation in maximum magnitude as a function of time. Figure 5b is a moving three point average of Figure 5a. There appears to have been a decrease in the maximum magnitude recorded in both levels since May 1988. This trend is more noticeable for the backfilled site. The maximum magnitude is also larger for the backfilled panels than for the unfilled panels; this correlates with a decreased b value for the backfilled panels (Table 3).

The dyke was intersected by the backfilled panels between March 1989 and September 1989. However, with the unfilled panels the dyke had been mined early in 1988. Selecting the data from 10/87 to 3/89 may therefore include a large amount of seismic activity induced as mining in the backfilled panels approached the dyke. This may explain why the backfilled level experienced higher seismicity, and therefore a larger amount of released seismic energy, than the unfilled level.

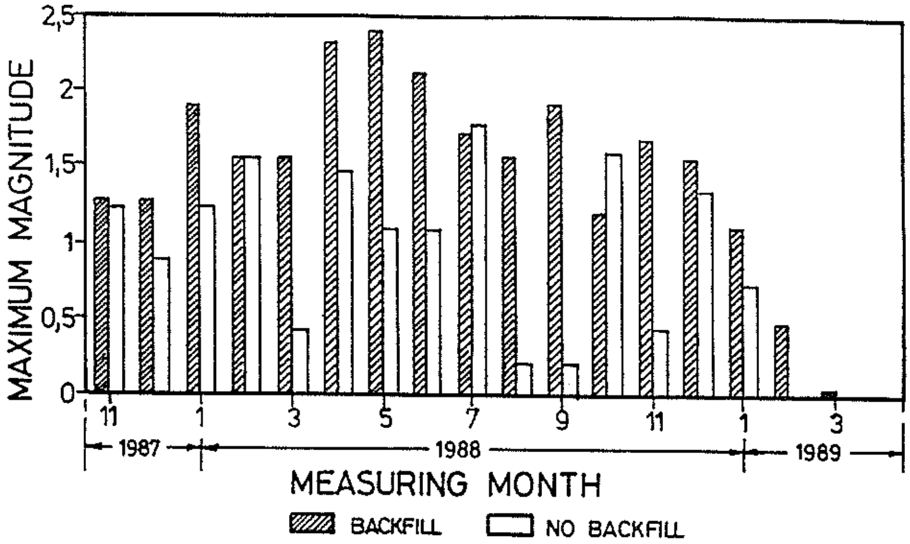

Figure 5a <u>MAXIMUM MAGNITUDE AS A FUNCTION OF TIME - WESTERN DEEP LEVELS - RAW DATA</u>

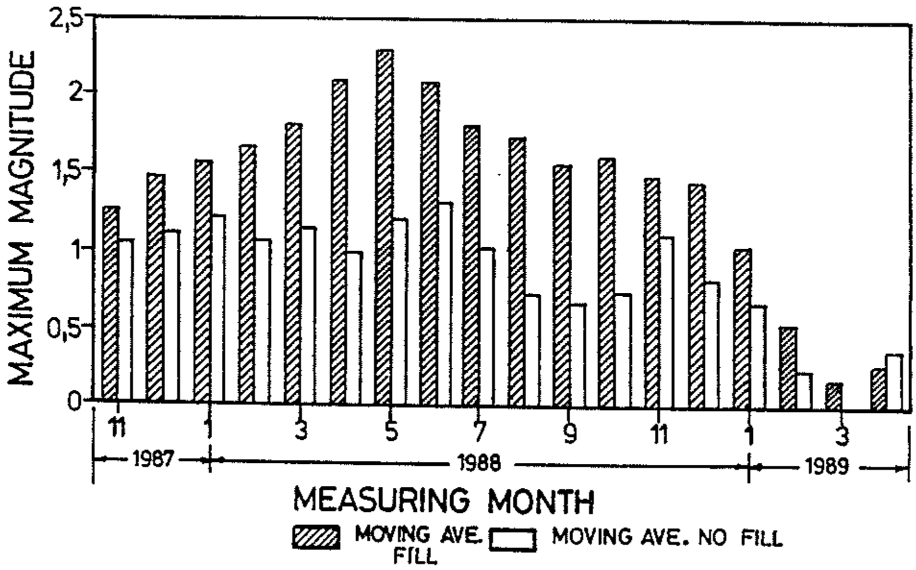

Figure 5b <u>MAXIMUM MAGNITUDE AS A FUNCTION OF TIME - WESTERN DEEP LEVELS - SMOOTHED DATA</u>

4.3 Vaal Reefs 2K Area

Table 4 contains a summary of the seismic data for this area.

There is an increase in the total number of events recorded during the period when mining was taking place with backfill, but this increase is restricted to the lower magnitude ranges, i.e. the majority of additional events have magnitudes less than two.

Values for the total energies released confirm these findings, since both the total and normalised values are larger for the time period of mining without backfill. During the period of mining with backfill the energy is being released in a large number of small events and a small number of large events. The reverse is true for the period of mining without backfill.

Table 4 SEISMIC PARAMETERS FOR VAAL REEFS 2K AREA FROM 1978 - 1990

	No Backfill	Backfill
Time Period No. of Months	7/78-6/84 72 months	7/84-12/89 66 months
Area Mined (m^2)	262 606	371 204
Total Events Events $1 < M < 2$ Events $2 < M < 3$ Events $M > 3$	116 54 20 11	249 111 37 6
Total / 1 000 m^2 $M > 1$ / 1 000 m^2 $M > 2$ / 1 000 m^2 $M > 3$ / 1 000 m^2	0.4 0.3 0.1 0.0	0.7 0.4 0.1 0.0
Total Energy Released (MJ) Energy / 1 000 m^2	$9.19x10^5$ $3.50x10^3$	$8.10x10^4$ $2.18x10^2$
b Value Error in b	0.50 0.10	0.66 0.10
γ_M	2.33	0.15

The b value listed in Table 4 is larger for mining with backfill than without backfill. This also implies a smaller ratio of large to small events for mining with backfill than for mining without backfill.

The γ value is significantly smaller for the period of mining with backfill, suggesting that less seismic energy is released per volume of rock mined. The large γ value for the period of no backfilling may indicate an external energy source, i.e. seismicity from outside the area of interest contributing towards the calculated released energy.

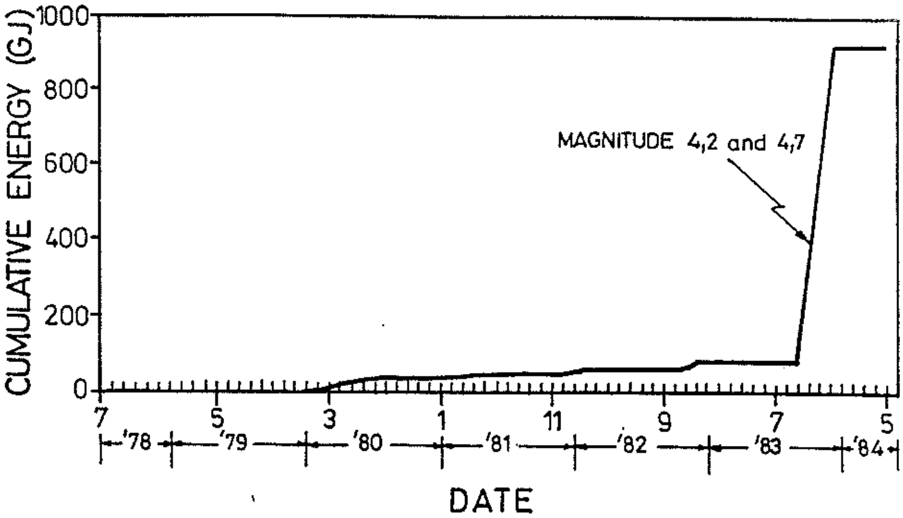

Figure 6a CUMULATIVE SEISMIC ENERGIES - VAAL REEFS 2K AREA - NO BACKFILL

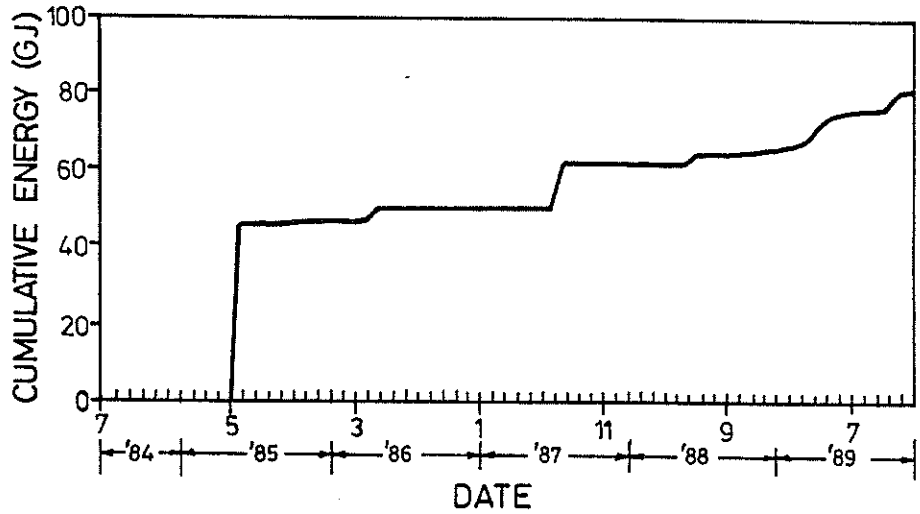

Figure 6b CUMULATIVE SEISMIC ENERGIES - VAAL REEFS 2K AREA - BACKFILL

Plots of the cumulative energy values for the two time periods 7/78 - 6/84 (mining without backfill) and 7/84 - 12/89 (mining with backfill) are shown in Figures 6a and 6b, respectively. From these figures it is evident that approximately 10 times as much energy is released during mining without backfill as during mining with backfill. The cumulative energy pattern for the unfilled time period is, however, governed by two very large events (magnitude 4.2 and 4.7) which occurred on 23 and 28 January 1984. The cumulative energy values during mining with backfill show a flattening off after about a year of backfilling. This implies that energy is being released in a large number of small energy packets rather than a small number of large energy packets.

In addition, mine management reported that, after the introduction of backfill, production in the 2K area had improved considerably since fewer days were required to open up working areas after a seismic event and that there was a decrease in the reportable rate due to falls of ground in the area.

For this data set γ_M values were calculated for each year of five years to show the temporal variation of this parameter. The values are listed in Table 5.

It can be seen from Table 5 that there are pronounced differences in the γ values for the unfilled and backfilled sites. During the period of no backfilling the γ values are around one (apart from 1984), whereas after the introduction of backfill they drop to around 0.3. This confirms the previous findings that backfill has reduced the amount of energy released due to mining.

Table 5 γ_M VALUES FOR THE VAAL REEFS 2K AREA

No Backfill		Backfill	
Year	γ_M Value	Year	γ_M Value
1980	1.47	1985	0.06
1981	1.06	1986	0.06
1982	1.10	1987	0.33
1983	0.95	1988	0.27
1984	9.58	1989	0.35

The large value of γ for 1984 results from the two very large events (magnitudes 4.2 and 4.7). It is very unlikely that these events were the direct result of mining within the study region. A magnitude 4.7 event has a source radius of approximately 1 600 m, whilst a magnitude 4.2 event has a source radius of approximately 900 m (Spottiswoode, 1984). The study region is approximately 600 m square, indicating that mining outside the area monitored contributed to these events.

5 CONCLUSIONS

The results obtained from this study are somewhat inconsistent but encouraging.

- The data from West Driefontein showed an increase in seismicity during mining with backfill. This increase was not restricted to a particular magnitude range. It was, however, directly related to mining in the proximity of a seismically active dyke. Including the seismicity associated with the period of no mining with that of the previous three months of mining without backfill yielded normalised energy release values and γ values that were smaller after the introduction of backfill compared to the period of no backfilling.

- The data from Western Deep Levels 83 - 95 level showed a marked decrease in seismicity with the use of backfill. This reduction was more pronounced for events with large magnitudes.

- The data from Western Deep Levels 85 - 90 level showed an increase in seismic energy released during mining with backfill, compared to mining without backfill. There was, however, a decrease in the seismicity level just prior to the mining of the seismically active dyke in the area. Furthermore, ERR values and seismicity levels did not appear to be directly related.

- Finally, the data from Vaal Reefs 2K area showed an increase in the number of events recorded during backfilling, compared to the period of no backfilling, but this increase was restricted to events in the lower magnitude ranges. There was an associated decrease in the number of events with magnitude greater than three. This result manifests itself in an increase in the b value after the introduction of backfill. Furthermore, the effectiveness of backfill in reducing seismic energy was seen in a reduction in the γ value for the period during which backfilling was taking place.

It would appear from these data sets that a factor complicating the evaluation of backfill on seismicity is the presence of geological structures in each area. In order to obtain an accurate assessment of the influence of backfill on seismicity, it is necessary to compare data sets which either have the same geological features, or have no geological features.

Nevertheless, the results from this study are encouraging in that it has been shown that (in some cases) the seismicity has been reduced in areas where backfill is being placed.

A re-evaluation of this topic is likely to take place during 1991 with new sites, new data sets and more advanced analysis tools.

6 ACKNOWLEDGEMENTS

The work described in this report forms part of the backfill research programme of COMRO. The co-operation of Management and Staff at West Driefontein Gold Mine, Western Deep Levels, Ltd. and Vaal Reefs Expl. and Mining Co., Ltd. is gratefully acknowledged. We would also like to thank R.G. Gürtunca for his help and support.

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APPENDIX I

I.1 CALCULATION OF FREQUENCY MAGNITUDE STATISTICS

The frequency magnitude statistics are the values a and b in the equation :

$$\mathrm{LOG}\ N(M) = a - bM$$

where N is the number of events with magnitude greater than or equal to M. The parameters a and b are computed by the maximum likelihood method, i.e. the formula derived by Utsu (1965) in a form given by Aki (1965) is used:

$$b = \mathrm{LOG}(e)/(M_{ave} - M_{min})$$

where LOG(e) is approximately 0.4343, M_{ave} is the average magnitude and M_{min} is the smallest magnitude that is detected with '100 per cent' certainty by the network.

The a value is calculated according to:

$$a = \mathrm{LOG}[N(M_{min})] + b$$

where $N(M_{min})$ is the number of events with $M > M_{min}$.

The uncertainty in b can be calculated at the 90 per cent confidence level from:

$$\sigma = 1.96 \times b / (N)^{1/2} \qquad \text{Aki (1965)}$$

I.2 CALCULATION OF γ VALUES

McGarr (1976) presented a method for equating the elastic change in volume due to mining, ΔV_E, with the seismic deformation due to the volume change. This relationship was written as:

$$\Sigma M_0 = \gamma_E G\ [\Delta V_E] \qquad \text{McGarr (1976)}$$

where ΣM_0 is the sum of the seismic moments of the population of seismic events and G is the rigidity or shear modulus. The factor γ_E is the ratio of cumulative seismic moment to volumetric moment, meaning that it is a direct measure of the seimic deformation associated with elastic closure due to mining. Like the b value, it is probably a function of geological conditions.

Assuming an average stoping width of 1 m, the area mined can be taken as a measure of volume change, ΔV_M. Strictly speaking, this leads to γ_M values. The γ_E and γ_M values are related by the following equation:

$\gamma_E = (2\gamma_M ERR)/\sigma_V$

where ERR is the elastic energy release rate and σ_V is the overburden pressure.

Following Webber (1989), γ_M values were calculated in this report by using the total areas mined in Tables 1, 2 and 4 to obtain ΔV_M.

It can easily be shown that

$\Sigma M_0 = 20000 \, \Sigma E$

where ΣE is the total seismic energy released (values in Tables 1, 2 and 4 in Joules). Therefore

$\gamma_M = 20000 \, \Sigma E/(G \Delta V_M)$

It is possible that γ is a parameter which indicates the likelihood of the rock to deform seismically during the relaxation of deviatoric stresses in a volume of rock. Also, a γ value greater than one means that the seismic energy generated by the system is greater than the energy induced by the mining. This implies that there must be an additional energy source ouside the area of interest.

The average rigidity modulus used in this analysis is 3.0×10^{10} N/m^2.