# Petroscopic observations of rock fracturing ahead of stope faces in deep-level gold mines

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### SYNOPSIS

The pattern of mining-induced fractures ahead of stope faces in deep-level gold mines, as revealed by petroscopic observations, is described. It is shown that there are zones of fractured and unfractured rock ahead of the face, which are about 1 m wide and continue as discrete entities for at least 12 m parallel to the face and at least 5 m vertically. These zones do not form continuously as mining progresses, but develop from time to time, leaving a solid zone between the fractured zones. The maximum depth of fracturing ahead of the face depends on the rate of energy release.

### SAMEVATTING

Die patroon van deur mynbou geïnduseerde breuke voor afboufronte uit in diepvlakgoudmyne soos aan die lig gebring deur petroskopiese waarnemings, word beskryf. Daar word getoon dat daar sones van gebreekte en ongebreekte rotsgebiede voor die front uit is wat ongeveer 1 m breed is en as afsonderlike entiteite voortgaan vir minstens 12 m parallel met die front en minstens 5 m vertikaal. Hierdie sones vorm nie deurlopend soos die ontginning vorder nie, maar ontwikkel van tyd tot tyd met 'n soliede sone tussen die gebreekte sones. Die maksimum breekdiepte voor die front uit hang van die tempo van energievrystelling af.

## Introduction

In the gold mines of the Witwatersrand, the extraction of gold-bearing ore often takes place at depths between 2 km and 3 km below the surface, and it is well known that a region of fractured rock is formed around tunnels and stopes.

It has been thought that the development of fractures ahead of an advancing stope face occurs as a regular progression of new fractures forming ahead of the failed zone of rock at the face. Zones of intense fracturing parallel to the face that occur in a regular pattern and are spaced about 1 m apart have been observed on the hangingwalls of some stopes. This pattern has been attributed to the concentration of fracturing in the region of very high stresses that are generated immediately in front of the face. An instantaneous advance of about 1 m is achieved with blasting, and the high stresses are displaced by the same distance to give rise to a second zone of intense fracturing ahead of the new face position. The time interval between blasts, 24 to 120 hours, has also been regarded as significant since this would allow 'time-dependent fracturing' to continue developing for a substantial period.

Detailed mapping of the fractures in the hangingwall at the Chamber of Mines' mechanized rockbreaking site at Doornfontein Gold Mine has revealed a similar pattern of fracturing. This observation eliminates blasting as an explanation for this phenomenon.

It was not known whether the fracturing seen in the hangingwall of stopes was representative of the fracturing that occurs ahead of the stope. The state of fracture of the rock adjacent to and ahead of a face is of importance to both conventional and mechanized mining. A comprehensive investigation was therefore initiated into fracturing ahead of stopes by petroscopic observations in boreholes that had been drilled into stope faces. Previous petroscopic work by Cloete *et al.*[1], in which boreholes were drilled back towards an advancing blasted stope from a predeveloped drive at a depth of 2073 m, showed that, although some fractures occurred 5 to 6 m ahead of the face, the main fracture zone was confined to a region no more than 1 m from the face. The zone consisted of closely spaced distinct fractures running parallel to the face.

This paper describes some of the results of an investigation that was undertaken at various mines to establish the extent of the zone of fracturing and the pattern of rock failure that occurs ahead of advancing stope faces. It was started at the mechanical rockbreaking site at Doornfontein Gold Mine, which provided a unique opportunity for the observation of stress-induced fractures in an area that was unaffected by blasting since the face was mined by mechanical rockbreaking machines. The type of support used at this site is also different from that currently being employed in conventional blasted stopes, that is, the waste rock is sorted in the stope and is hand packed to produce a solid-waste fill.

As the fracture pattern observed at the mechanized rockbreaking site was different from that reported by Cloete *et al.*[1], the investigation was extended to blasted stopes to observe the effects of mining by blasting and the rate of energy release on the fracture pattern.

## Observation and Mapping of Fractures

BX-size boreholes were drilled with a standard pneumatic machine directly into the face in a direction perpendicular to the face for a distance of approximately 10 m. Difficulty was experienced with the drilling, and the drill bits wore rapidly. The maximum rate of drilling was about 5 m per shift, and approximately 60 per cent of the core from each borehole was recovered.

The petroscope used for these observations was made in the Chamber of Mines' instrument workshop. It is cylindrical in shape and has a diameter of 38 mm. It is inserted into a borehole with the aid of extension rods. In the centre of the petroscope is a mirror inclined at an

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angle of 45 degrees to the axis of the instrument. On either side of the mirror is an electric light that receives power, via a trailing cable, from a small battery in the stope. The wall of the borehole near the mirror is well illuminated, and an image of the wall is reflected down the borehole by the mirror and is observed by a telescope placed on a tripod in the stope in line with the borehole. With a camera attached to the back of the telescope, it is possible to photograph the fractures.

To observe the entire borehole, the petroscope is inserted gradually and is rotated by the extension rods. The position and orientation of the fractures are determined from the length of rod inserted into the borehole when the mirror is opposite the intersection of the fracture with the top and both the up and down dip sides of the borehole. It is then a matter of simple geometry to work out the orientation of the fracture with respect to the axis of the borehole.

The boreholes were observed every few days, and the position and direction of the fractures were logged after each observation. The position of the face relative to a reference point was also noted as the face advanced during the period of observation.

## The Rockbreaking Site

The rockbreaking site is part of a longwall face at Doornfontein Gold Mine, and is 450 m long. This part of the longwall face is being advanced by mechanical rockbreaking machines, and no blasting takes place during either face or gully advance.

The longwall face is 2300 m below the surface and dips at approximately 22 degrees. Two rows of rapid-yielding hydraulic props are used for immediate stope support. Permanent support is provided by waste rock, which is sorted after mining and packed tightly between the hangingwall and the footwall, being maintained at a distance of 4 to 5 m behind the face.

The important geological features in the area are two dykes of different orientations with associated faults and fractures, a persistent and penetrative quartz-vein trend, and bedding planes. The reef mined is the Carbon Leader. Most of the holes were drilled in the subglassy, medium-grained quartzites that form the hangingwall of the reef and that have a uniaxial strength of between 200 and 300 MPa.

Roering[2] has observed mining-induced fracturing in the stope behind the face. These fractures can be classified into three types, all striking roughly parallel to the face. The first group, which makes up the majority of the fractures, dips steeply at angles greater than 80 degrees. The second group dips at angles of 60 to 70 degrees both towards and away from the face, commonly forming what appear to be conjugate pairs. These fractures usually show the normal fault type of displacement of up to 120 mm. The third group dips towards the face from the mined-out side at angles of between 20 and 40 degrees. The first two groups of fractures form intensely fractured zones, while the third group commonly occurs in the less fractured regions separating these zones.

## Petroscopic Observations at the Rockbreaking Site

Figs. 1 and 2 illustrate a typical series of fracture diagrams (plan views) for two boreholes. The diagrams

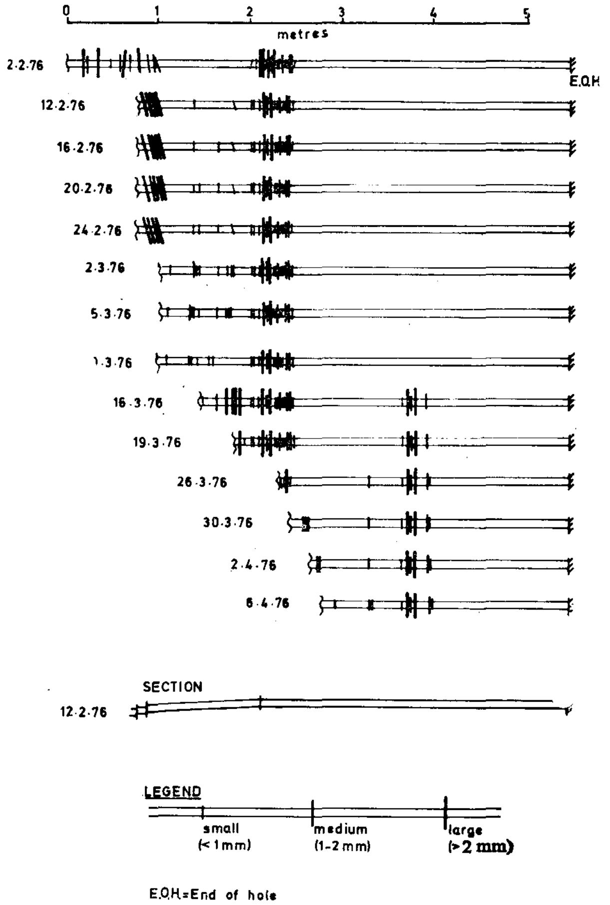

**Fig. 1—Plan view of petroscope hole 1 with fracture observations on the dates shown, the energy-release rate in this area being 19 MJ/m$^2$**

for each observation appear below one another in the order of date in which the observations were taken so that the change in the fracture pattern and the advance of the face can be recognized. At the bottom of the first figure is a section through the hole showing the way the hole has been dislocated as a result of displacement of the rock on a fracture ahead of the face.

The observations showed that all the boreholes had zones of concentrated fracturing separated by relatively solid blocks, which were about 1 m thick. The fractured regions consisted of distinct fractures 5 to 150 mm apart that effectively broke up the rock into thin vertical lamellae. In some instances, the blocks between the zones of intense fracturing contained a few small fractures.

Most fractures were clearly open. Some fractures, which were more than 1 m ahead of the face, had a gap width of about 10 mm. Fractures that were not open were either filled with white, comminuted rock material or had an irregular, broken surface.

It was found that most fractures strike in a direction approximately parallel to the face and have a dip within 20 degrees of the vertical. In Fig. 2, a group of fractures, 4 to 6 m down the borehole, is depicted that are not parallel to the face but have the same strike as one of the three sets of geological structures mapped in the stope. It is probable that most of these fractures are geological in origin.

Low-angle fractures, with dips of less than 40 degrees, were observed in some of the boreholes. The few that were recorded were within 0,5 m of the stope face. It is not possible to positively identify the conjugate pair fracturing, identified by Roering[2], by petroscopic observations of a single borehole. However, pairs of fractures with dips that would correspond to this form of fracturing were observed up to 4 m ahead of the face.

As the face advanced, existing fractures opened up and new fractures formed. The total depth of fracturing ahead of the face did not remain constant, that is new fractures did not form in the solid rock at the same rate as the face advanced. Instead, a new fracture zone formed suddenly from time to time. Some new fractures also formed very close to the face, but this was not always the case. It was also noted that no significant fracturing occurred when the face was not mined for a few days. (See Fig. 1, 3rd to 5th observations covering a period of eight days.)

There were occasions when the stope was mined

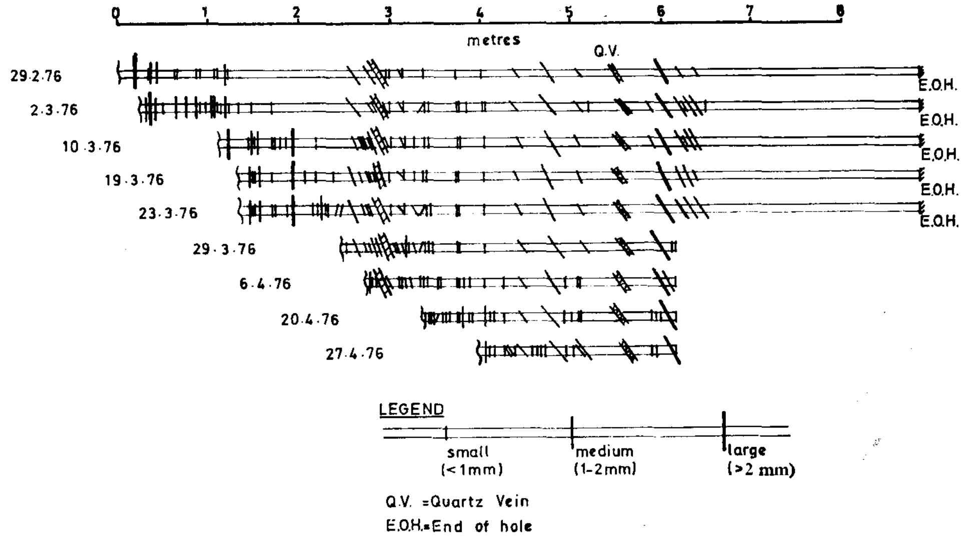

Fig. 2—Plan view of petroscope hole 2 with fracture observations on the dates shown, the energy-release rate in this area being 26 MJ/m$^2$

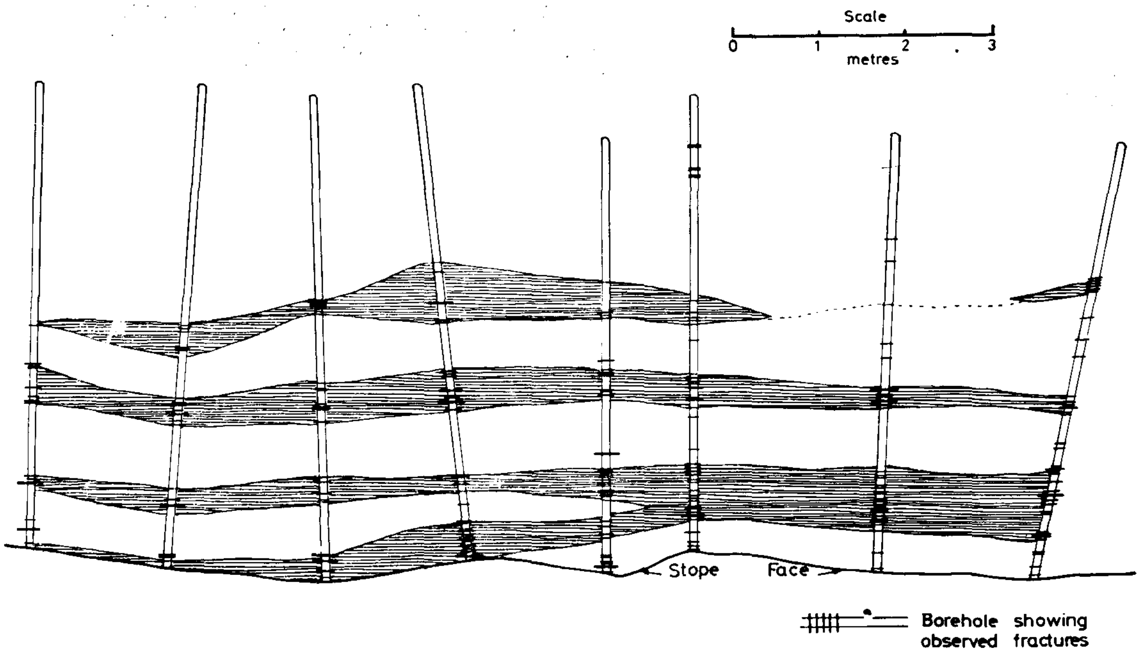

Fig.3—Plan showing eight petroscope holes and the estimated lateral extent of the fracture zones

through a solid block without the block fracturing. The reasons for the lower stress condition on these blocks are not known.

In several cases, vertical movement took place at a fracture, displacing the borehole so that it was not possible to insert the petroscope down the full length of the hole. The direction of relative movement was almost invariably up on the side away from the stope.

Slight spalling was observed in the sidewalls of the boreholes in the solid regions between the fractured zones, but not in the fractured zones.

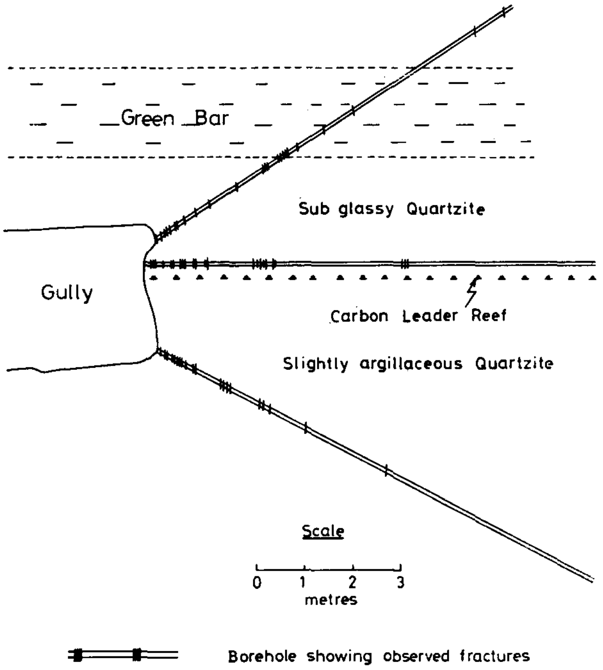

**Fig. 4—Section through three petroscope holes indicating vertical extent and degree of continuity of fracturing**

Discing was observed in almost all the cores from the petroscope holes. It was confined to those regions that were found to be unfractured when the hole was examined with a petroscope, that is the core corresponding to the fractured zones in the hole did not disc while some of that corresponding to the solid zones did. Further, in some cases it was noted that the discs were thinner towards the centre of a particular solid zone and thicker towards the outside, that is towards the fractured zones. This indicated that the stress in the middle of the solid zones is higher than at the edge adjacent to the fracture zones.

The New Minsim (Newmip[3]) digital computer program was used to calculate the energy-release rate in the areas where the holes shown in Figs. 1 and 2 were situated. The values were 19 MJ/m$^2$ and 26 MJ/m$^2$ for the two areas respectively. The depth of fracturing never exceeded 2,5 m in the lower energy-release areas, but extended up to 6 m where the energy-release rate approached 30 MJ/m$^2$.

Fig. 3 is a plan showing the fracturing that was observed in eight boreholes drilled at intervals of approximately 2 m. The fractured zones are discrete entities 0,3 to 1,3 m wide, and can be traced parallel to the stope face for at least 12 m on dip. Individual fractures do not necessarily continue for that distance, but the zones of solid and fractured rock do.

Fig. 4 is a section through a gully showing the fractures observed in three holes drilled in the same vertical plane; the vertical extent of the fracture zones is at least 5 m. (However, stope-related fractures have been observed at a depth of 45 m in footwall development ends.)

This pattern of fracturing is typical of the mechanically mined waste-packed stope at Doornfontein. Many other petroscopic observations at the same site have given an almost identical picture.

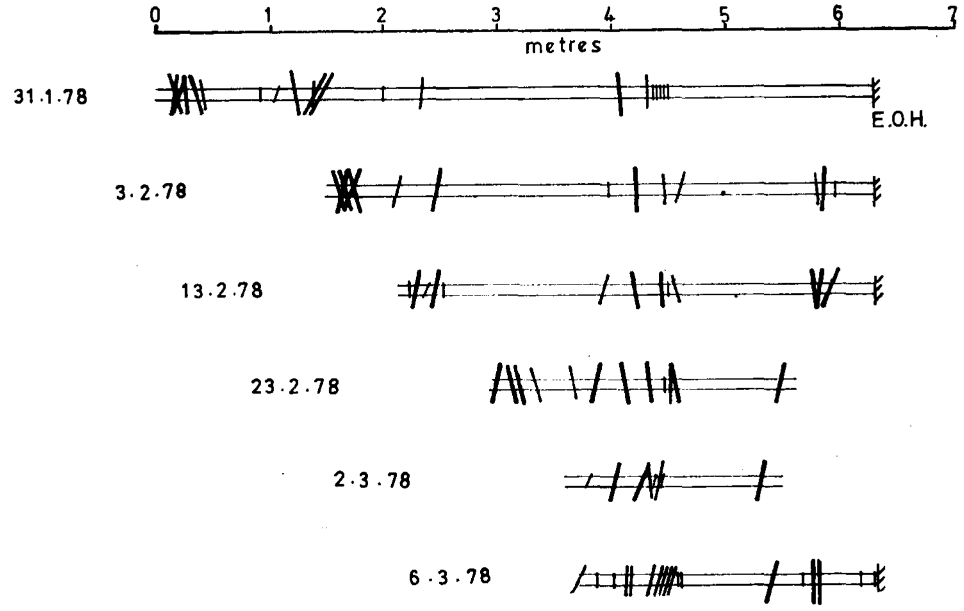

**Fig. 5—Plan views of petroscopic observations of a hole in a blasted stope with an energy-release rate of 17 MJ/m$^2$**

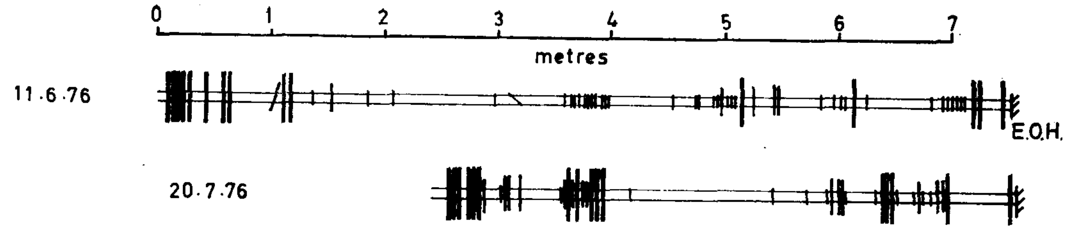

Fig. 6—Plan views of petroscopic observations of a hole in a stope with an energy-release rate of 75 MJ/m$^2$

## Petroscopic Observations at Other Sites

Having established that there was a consistent pattern of fracturing at the mechanically mined waste-packed site, it was decided to extend the investigation into other areas to examine the effect on fracturing of mining by blasting, conventional support, and changes in the rate of energy release.

Fig. 5 is a series of fracture diagrams for a hole drilled into a blasted stope where the energy-release rate was 17 MJ/m$^2$. The features are similar to those observed at the rockbreaking site shown in Fig. 1, namely

(1) discrete fracture zones are separated by areas of solid rock,
(2) new fracture zones formed in the solid rock with an area of unfractured rock between them and the last fracture zone,
(3) new fractures developed in the solid rock adjacent to the face as the face advanced, and
(4) the maximum depth of fracturing in each observation varied between 3 and 4 m.

Fig. 6 illustrates two observations made in a stope where the energy-release rate was 75 MJ/m$^2$. It can be seen that the fractures extended to a depth of at least 7,5 m, the depth of the hole, and that there was a rudimentary arrangement of fractures into solid and fractured zones. In the second observation made ten weeks later, after the face had been advanced by 2,5 m, one of the fracture zones had grown considerably and the fractures in the ground behind it had closed up so that the ground appeared solid.

A range of energy-release rate environments has been available for study outside the mechanized stope at Doornfontein. Fig. 7 shows typical fracture patterns observed at different levels of energy-release rate. At low levels, only one band of fractures close to the stope face is present but, as the energy-release rate increases, more zones of solid and fractured rock are developed further ahead of the face, indicating that the distance for which rock is fractured ahead of stope faces is dependent on the energy-release rate. It also shows that the effect of increasing energy-release rate is more to increase the depth of fracturing ahead of a stope than to increase the density of fracturing. All the boreholes depicted in the diagram were drilled in subglassy to glassy quartzites. The

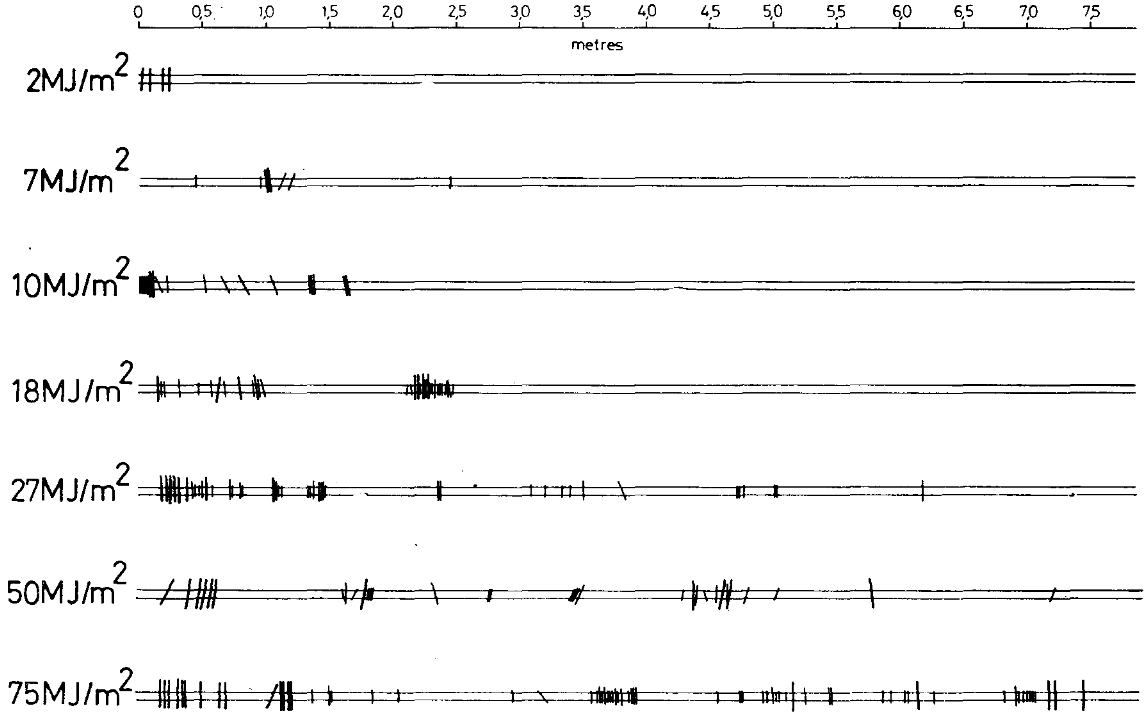

Fig. 7—Diagram showing extent of fracturing ahead of stopes mined at different levels of energy-release rate

increase in depth of fracturing with increasing energy-release rate as shown in the diagram cannot therefore be attributed to a variation in rock strength.

## Conclusions

Petroscopic observations have revealed a pattern of mining-induced fracturing ahead of stope faces that is significantly different from that previously thought to exist.

From the many observations made at the Doornfontein mechanized rockbreaking site, it is clear that fractures ahead of the stope face form in discrete zones about 1 m wide separated by zones of solid rock, again about 1 m wide. These zones were traced laterally for as much as 12 m and vertically for 5 m. The maximum distance of fracturing ahead of the stope face appears to be dependent on the rate of energy release.

As the face is mined towards one of the solid zones separating the bands of fractures, this solid zone often fractures, but the fracturing is less intense than in the original fracture zones. However, situations do occur where the rock at the face remains completely unfractured.

The formation of fractures is directly associated with face advance. The majority of new fractures develop shortly after the face is mined. Little fracturing takes place while the face stands, and, when a face was not mined for a period of 14 days, no fractures formed.

Although fewer observations were made in blasted stopes, some tentative conclusions can be drawn. The maximum distance of fracturing ahead of the stope face appears to depend on the rate of energy release. Except in the area where the energy-release rate was below 5 MJ/m$^2$, zones of solid and fractured rock were also found. As the energy-release rate increases, more of these zones are formed and they extend further into the rock.

No explanation can yet be given as to why fractures form in discrete zones separated by solid rock, but work is continuing on this problem, which is fundamental to an understanding of fracture phenomena around deep-level stopes.

## Acknowledgements

Many of the initial observations at the mechanical rockbreaking site were made by R. J. van Proctor, who has left South Africa and was therefore unable to collaborate in writing this paper. The assistance of various mining companies in providing the sites at which the observations were made is gratefully acknowledged.

## References

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2. Roering, C. R. The influence of geological structures on the instability of rock in and around a deep mechanized longwall stope. To be published.
3. Moris, J. P. E., and Godfrey, J. B. Shallow Minsim and New Minsim. A user's reference. Private communication.

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# Exploration planning

Following the success of the seminars on Economic Guidelines for Exploration Planning in September 1979, Professor Brian Mackenzie of Queen's University, Kingston, Ontario, will be presenting a similar series of seminars at Rhodes University from 1st to 6th September, 1980.

The seminars are intended for senior personnel involved in mineral exploration planning and management. There are only 30 places available for the seminars and these will be allocated as equitably as possible. The seminars are designed to give a practical insight into the important aspects of financial analysis, mineral economics, and exploration planning and management.

The seminars will be conducted at the Settler's Motel, Grahamstown, under the auspices of the Geology Department, Rhodes University.

The provisional topics are as follows:

Introduction
The Concepts of Cash Flow and Time Value
Discounted Cash Flow Methods
Mining Taxation Considerations
Evaluating Exploration Projects
Exploration Economics and Strategies
Structuring Exploration Agreements
Risk Analysis Techniques
Economic Guidelines for Finding and Acquiring Mineral Deposits
Establishing Minimum Acceptable Exploration Target Conditions
The Decision Tree Concept for Exploration Planning

Enquiries should be directed to Mrs M. Jackson, Geology Department, Rhodes University, P.O. Box 94, Grahamstown 6140.