The importance of both geological structures and mining induced stress fractures on the hangingwall stability in a deep level gold mine

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Synopsis

The deep level gold mining environment is characterized by high stresses that give rise to intense mining induced fracturing of the rock mass surrounding the stopes. In a geologically disturbed region where the intensity of mining induced stress fracturing is high, the degree of faulting and/or the frequency of other geological features such as joints may pose serious strata control problems. Unfavourable intersection of these discontinuities namely, faults, joints and mining induced stress fractures tend to divide the immediate hangingwall into unstable keyblocks which, if not supported, may result in extensive falls of ground. Effective support strategies therefore demand detailed investigation of the predominant inclinations and orientations of these discontinuities.

The orientations and inclinations of these discontinuities surrounding a deep level stope have been measured. The results are projected onto the lower hemisphere of a stereographic net to determine the factors that contribute to the falls of ground in the stope. The analyses reveal that unfavourable intersection of these discontinuities divides the immediate hangingwall into unstable wedges that may become dislodged between support units.

Introduction

The mode of fracturing of the rock mass surrounding underground excavations is believed to be essential information for effective support design. Deep level, underground excavations are usually surrounded by an envelope of fractures that create stability problems. The primary objective of any support design is to maintain the integrity of the immediate hangingwall under dynamic and quasi-static loading conditions. When this objective is achieved, it ensures the accessibility of the working area and, more importantly, reduces the number of rock-related accidents. This dual function of support elements cannot, however, be accomplished in isolation. It requires the consideration of both the degree of fracturing around the stope and the presence of geological features such as parting planes, joints and faults. Ignoring these fundamental requirements could result in the ejection of unstable keyblocks which, if not effectively supported, could result in a rock-related accident.

As part of the strategies adopted to improve the understanding of the rock mass behaviour surrounding the Ventersdorp Contact Reef (VCR), a study of the fracture pattern of the soft lava overlying this reef at Kloof Gold Mine was considered to be essential. This was carried out on 33/27 longwall north and south panels. A summary of the observations made, emphasising the need to consider both fracture patterns and geological structures, is presented. Orientation analysis has been used to present the accumulated data, and photographs to substantiate these findings have been included.

Geological features

The long and complex tectonic history of the Witwatersrand basin (e.g. Roering *et al*[4]) has resulted in a complex fault and dyke pattern, which significantly influences the distribution of orebodies and impacts on rock mass behaviour. A detailed discussion of the tectonic history of the Witwatersrand basin is beyond the scope of this study. However, Berlenbach[1] has shown that faults associated with a north-east thrust event have had an important influence on the rock mass behaviour at Kloof Gold Mine. This thrust event indicates an older, north-westward verging thrust event, resulting in a complex reactivation of fault structures. Because thrust faulting has an important impact on rock mass behaviour in the study area, a brief discussion of the fault geometry and mechanisms is given. Reverse or thrust faults are inclined faults, with inclinations generally less than 45 degrees, with a zero or small strike-slip

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component displacement, and with a marked dip-slip component which gives an elevation of the hangingwall relative to the footwall. Low angle reversed faults of this type (dip less than 45 degrees) are frequently termed thrusts or thrust faults. Because thrust faults are the dominant faults in the study area, they are discussed in some detail.

In thrust systems, the displaced hangingwall block is termed a thrust sheet. Thrust complexes, made up of several thrust sheets, are sometimes bounded by a well-marked floor thrust, and may also be bounded by an uppermost roof thrust. Often a series of reverse faults branch from a floor thrust and produce a splay fault fan structure that is termed an imbricate structure. Such faults that splay off a common floor thrust, are called 'ramps'. In these structures, the strata are stacked like a reversed overlapping series of roof tiles.

Similarly, imbricate fans are subdivided, based on which of the subsidiary thrusts shows maximum displacement. Where the maximum slip occurs on the frontal fault, it is known as a leading imbricate fan (see Figure 1a), whereas an imbricated system where maximum slip occurs on the most internal fault is known as a trailing imbricate fan (see Figure 1b). Individual imbricate faults may terminate upwards, but more often they curve asymptotically towards a common roof thrust, so that the imbricate zone is contained between a roof and a floor thrust. Such a structure is termed a duplex (see Figure 1c). A more detailed description of the geometry, sequential initiation and development of these structures have been presented in Ramsay and Huber[3]. The dashed lines as shown on Figures 1a, 1b and 1c represent an imaginary displacement of the reef.

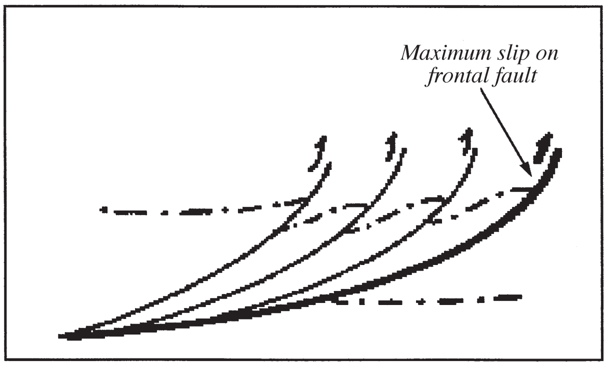

Figure 1a—Leading imbricate fan (Ramsay and Huber 1987)

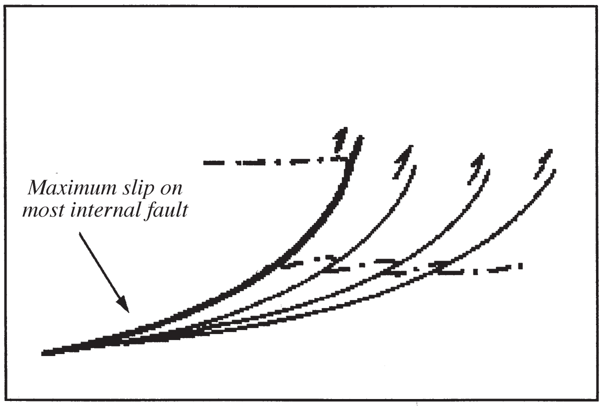

Figure 1b—Trailing imbricate fan (Ramsay and Huber 1987)

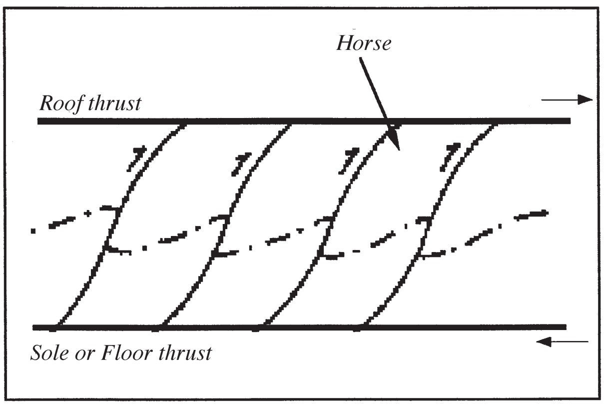

Figure 1c—Duplex structure (Ramsay and Huber 1987)

Mapping

The objective of this study was aimed at improving support design by acquiring knowledge about the inclination, orientation and intensity of the mining induced fractures in relation to geological features. The method adopted for gathering data involved mapping the inclinations and orientations of both mining induced fractures and geological features such as faults and joints. Basically, section lines were established along the strike of the hangingwall, from the stope face up to about 30 m in the back area. Measurements were taken along this line with a Brunton compass and frequently checked with a clino-rule to ascertain the possible influence of magnetic substances on the readings. Where necessary a correction was made for magnetic declination. The Brunton compass is an instrument used to determine azimuth angles or compass bearings (and thus to determine horizontal angles) to measure vertical angles, per cent of grade or slope, to run levels and to measure the inclination of objects. The clino-rule is a 1 m long device fitted with a water bubble and a linear scale for a quick estimation of the length and orientation of objects.

Orientation analysis

The lower hemisphere projection technique embedded in the DIPS (a computer program primarily developed for the interactive analysis of orientation-based geological data) was used to plot and analyse the data. A detailed description of the lower hemisphere projection technique has been given by Hoek and Brown[2]. The observations made in each of the two stopes are presented separately in the following subsections.

Observations in north panels

The study area is shown in Figure 2. Most of the mapping work was done in the first and second panels. Observations made in these panels revealed that thrust faults in the hangingwall seem to be the main geological structures traversing the area. Generally these are low dipping faults. Their surfaces are slickensided with the striations orientated towards the north-east. Quartz veins are common features.

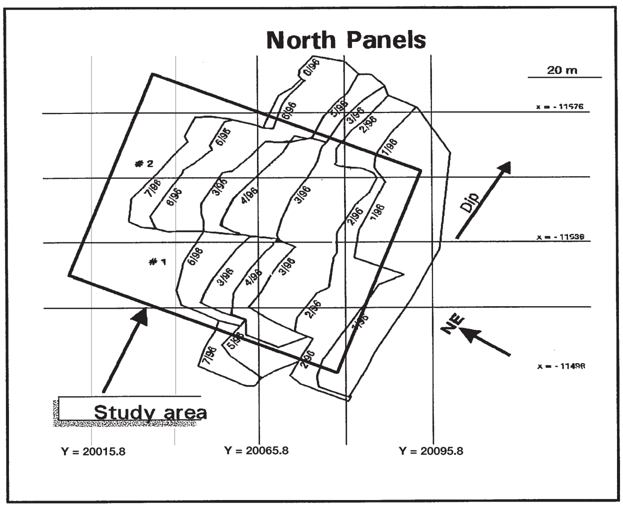

Figure 2—The study area in the north panels

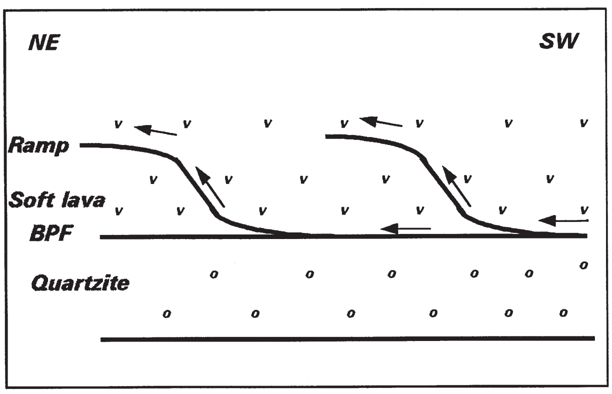

Figure 3—Simplified geometry of the imbricate system in the study area, bedding-parallel faults along the VCR/soft lava contact step up into the hangingwall along steeper dipping ramps. Arrows indicate movement directions

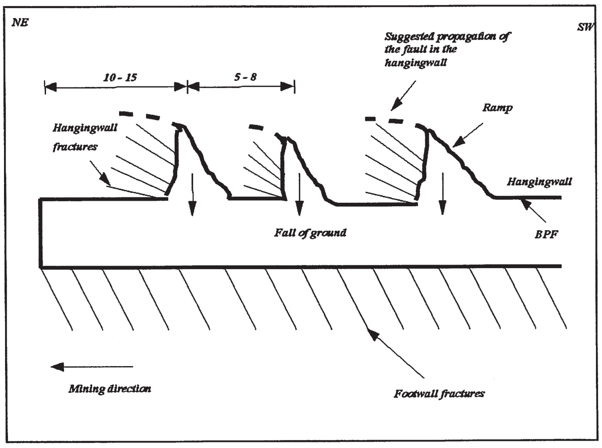

Figure 4—A simplified strike section showing the complex relationship between mining induced stress fractures and geological structures in the north panels

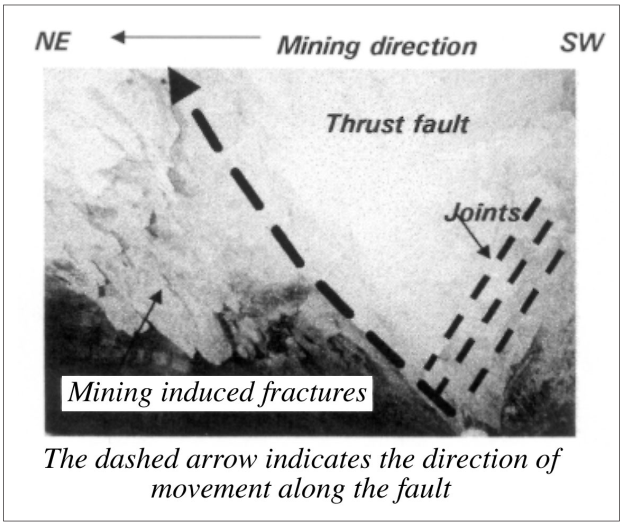

Figure 5—The orientation of mining induced stress fractures in the vicinity of geological structures in north 2 panel

These give an indication that there is a bedding parallel fault (BPF) at the contact between the VCR and the soft lava along which movement has taken place (Figure 3).

This bedding parallel fault can be regarded as a floor thrust. The low dipping thrust faults that appear to branch off from the main floor thrust into the soft lava, represent an imbricate structure. These structures were observed to occur along strike. Their point of inflexion was, however, not conspicuous although there seemed to be a recurrence of these structures at intervals of between 5–8 m along strike. On all occasions, their first occurrence was noticed at about 10–15 m from the stope face. The hangingwall within this interval was virtually smooth. Also, as the span increased, a fall of ground usually occurred which then exposed the structure. A typical distance of the area exposed stretched over about 13 m along dip and about 190 cm into the hangingwall. Figure 4 is a simplified section, indicating the complex relationship between these faults and the mining induced fractures. These observations are substantiated by the attached photographs, i.e. Figures 5 and 6.

The lower hemisphere projection technique has been used to analyse the data gathered. The results are presented in three separate diagrams in Figure 7. In all three cases, pole concentrations specifying the orientation of the structures have been contoured. The mean orientation of each of these structures has been deduced from the point of maximum pole concentration. Corresponding major planes have been drawn. In Figure 7a, the faults strike approximately face-parallel and dip steeply towards the back area. From underground observations mining induced stress fractures tend to cluster around the faults (see Figure 7b). In contrast, the joints appear to be dipping towards the stope face but strike approximately face-parallel as shown in Figure 7c. Figure 8 shows the adverse intersection of these structures which leads to the isolation of unstable 'triangular' blocks in the hangingwall.

Interpretation

The orientations of joints, faults and mining induced fractures have been presented separately in each of the diagrams. The major planes representing each of the projections are presented in Figure 8. The stippled region

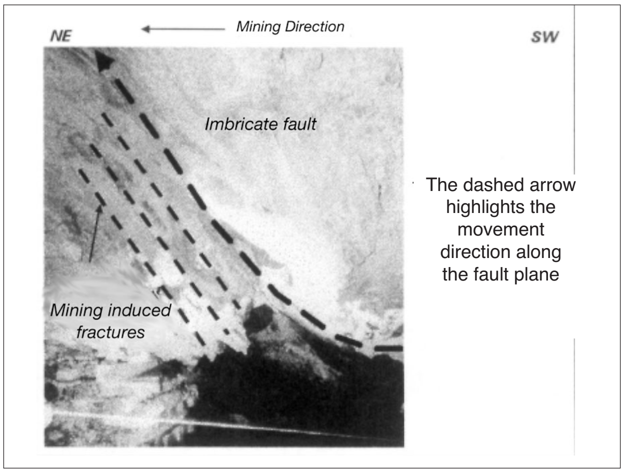

Figure 6—An illustration of the movement direction along a thrust fault in north 2 panel

demarcates an area bounded by these three structures in the hangingwall, and represents the typical shape of an isolated piece of rock that may be formed by the unfavourable intersection of geological structures and mining induced fractures. This accounts for the fall of ground patterns observed between the timber packs so that the orientation and inclination of these structures affects the stability of the hangingwall.

Observations in south 1 panel

Geological features, particularly the thrust faults as previously described, were not exposed in the southern stopes. However, there was some evidence that they do exist. The few that were exposed and could easily be identified had similar features (i.e. striations, slickensides and calcite or quartz veins) to those noted in the north panels. A characteristic feature believed to affect the stability of the hangingwall is a bedded quartzite layer which is quite common between the VCR and the soft lava. The average spacing between successive beds is 130 mm. The study area is shown in Figure 9.

Mining was being advanced on strike towards the south-west. The upper panels, labelled 1 to 4, were permanently stopped due to the extremely low grade of the reef. The mapping was mainly carried out in the fifth panel as shown in Figure 9. The mining induced fractures dipped towards the face and underground observations showed that they strike approximately parallel to the stope face. Unstable keyblocks were bounded by fractures dipping at various angles to the mining direction. An illustration of a strike section across the stope depicting the orientation of the fractures and probable thrust faults in the hangingwall is shown in Figure 10. Some underground photographs are shown in Figures 11 and 12.

Figure 13 shows the results of the stereographic projections of mining induced stress fractures. The bold line shows the strike of the reef and also indicates the direction of mining, i.e. towards the south-west. The orientation of the reef has been represented as a major plane dipping towards the south-east. Contours of the poles representing the orientation of the mining induced stress fractures have been

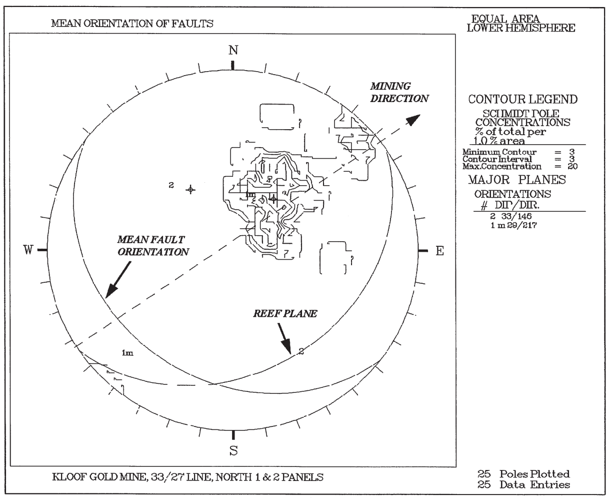

Figure 7a—Orientation of imbricate faults in the north panels

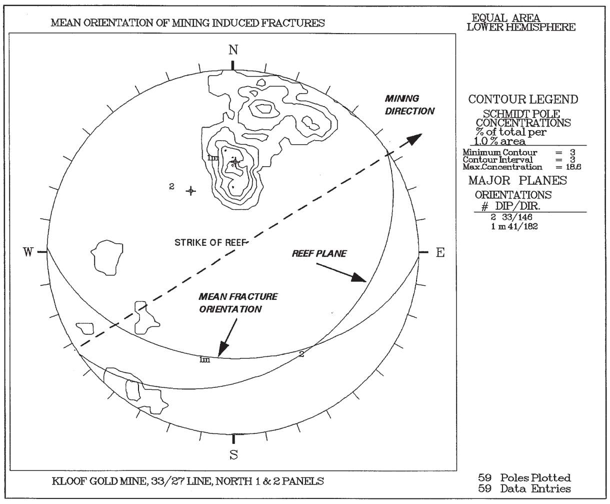

Figure 7b—Orientation of mining induced stress fractures in the north panels

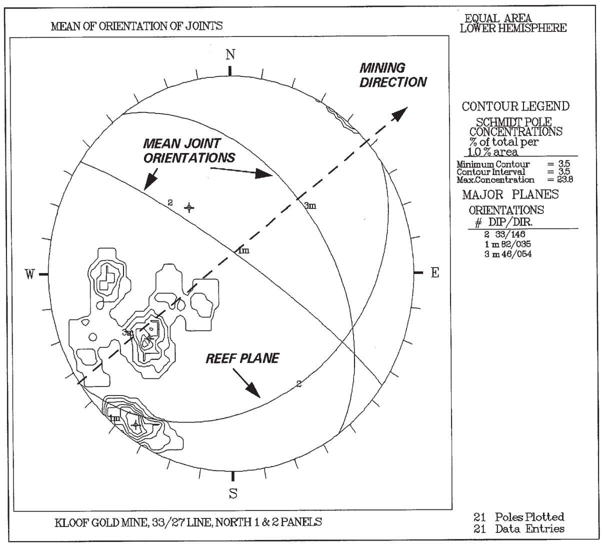

Figure 7c—Orientation of joints in the north panels

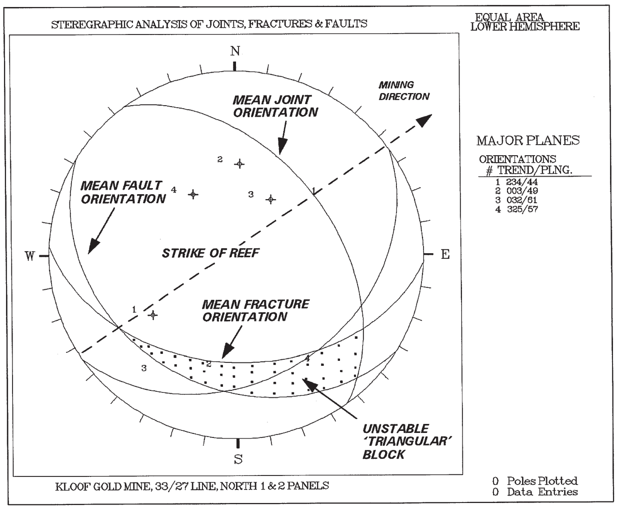

Figure 8—Intersection of joints, faults and mining induced stress fractures

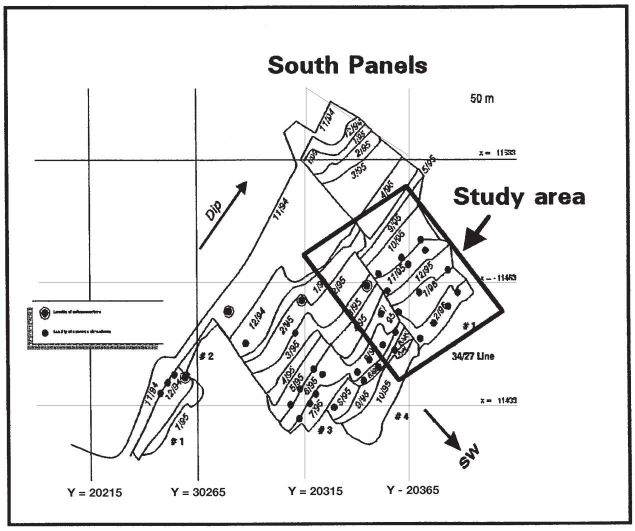

Figure 9—The study area in the south panels

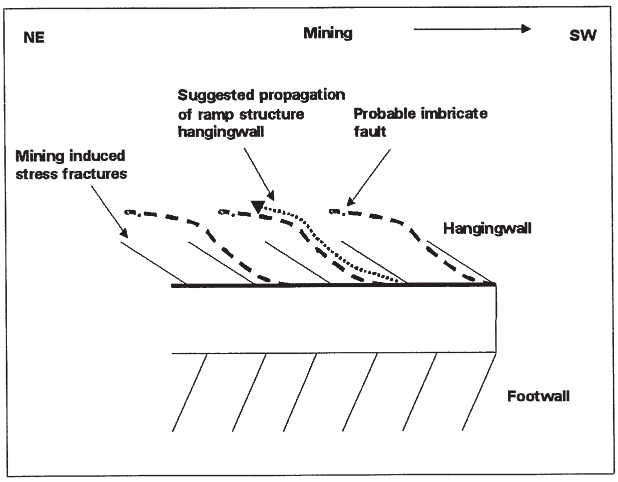

Figure 10—A simplified strike section showing the orientation of mining induced stress fractures and probable thrust faults in the south panels

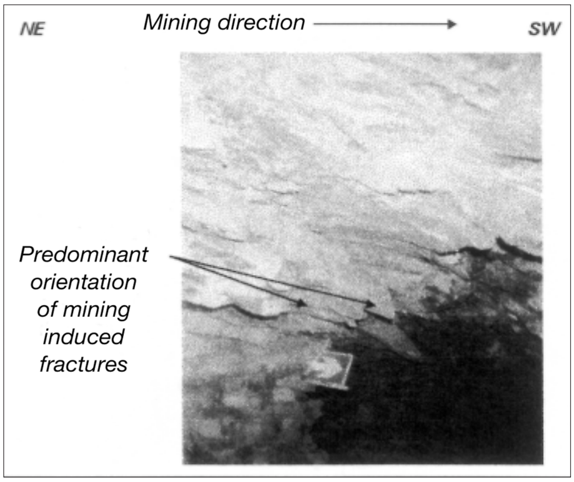

Figure 11—General orientation of mining induced fractures in the south panels

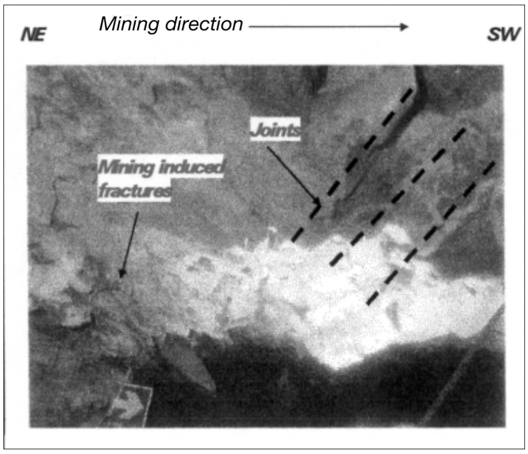

Figure 12—Unfavourable intersection of mining induced stress fractures and joints in south 1 panel

drawn. The contour plot displays three distinct concentrations of fractures. The first group dip steeply and are approximately face parallel. The second group of fractures is less steeply dipping and strike obliquely to the face. The last group consists of shallow dipping fractures that strike approximately perpendicular to the face. Major planes corresponding to each of these concentrations have been drawn as shown in Figure 13. The pole concentrations of these geological aspects do not feature prominently on the diagram due to their inconspicuous nature during the measurements.

Discussion

The general inclination of the mining induced fractures and the geological features have been presented. The results indicate that the stability of the rock mass depends on both geological features and mining induced stress fractures. The fracture orientation analyses also confirm that the rockfalls observed in the north panels are due to the unfavourable

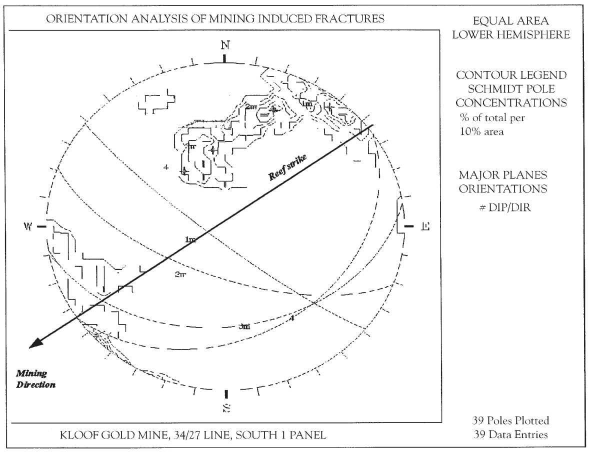

Figure 13—Stereographic projection of mining induced stress fractures in south 1 panel

intersection of both geological features and mining induced stress fractures.

The reversed orientation of the mining induced fractures and their clustering around the ramp structures in the north panels, suggest that their formation is to some extent influenced by these geological structures. The hangingwall appears to be more stable when advancing towards the S-W than in the N-E direction. However, this observation may not be justified, considering the fact that mining operations were halted permanently in the upper panels on the southern part of the longwall.

It is proposed that the extensive imbricate faulting in the area and the material properties of the soft lava, coupled with the tectonic history of the area, have contributed significantly to the characteristics of the rock mass.

In situ stress measurements were not carried out during the study. However, information about the pre- and post-mining stress regimes would help understand the mechanisms involved in their formation.

Conclusions

The findings in the soft lava-quartzite geotechnical area are peculiar to this particular geological environment. Imbricate faulting appears to be a major factor influencing the stability of the hangingwall. Thus, it can be concluded that, the design of support systems should take both geological features and mining induced fractures into consideration. The unstable condition of the hangingwall in the north panels suggests that a slight reduction in the strike spacing between support units could improve the hangingwall conditions. This implies that flexibility should be incorporated into mine support standards to allow for changes when the need arises. It should be possible to apply different strike support spacings in the south and north stopes.

Detailed investigations are recommended in future as this would further improve the understanding of the rock mass behaviour. These should include the following:

- The influence of geological features on the orientation of mining induced stress fractures
- Detailed mapping in a soft lava environment where mining is progressing on adjacent sides of a longwall. This would help to ascertain the direction of mining on the stability of the hangingwall
- *In situ* stress measurements would provide the principal stress orientations. This information would help to understand the mechanisms responsible for the observed direction of fracturing.

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